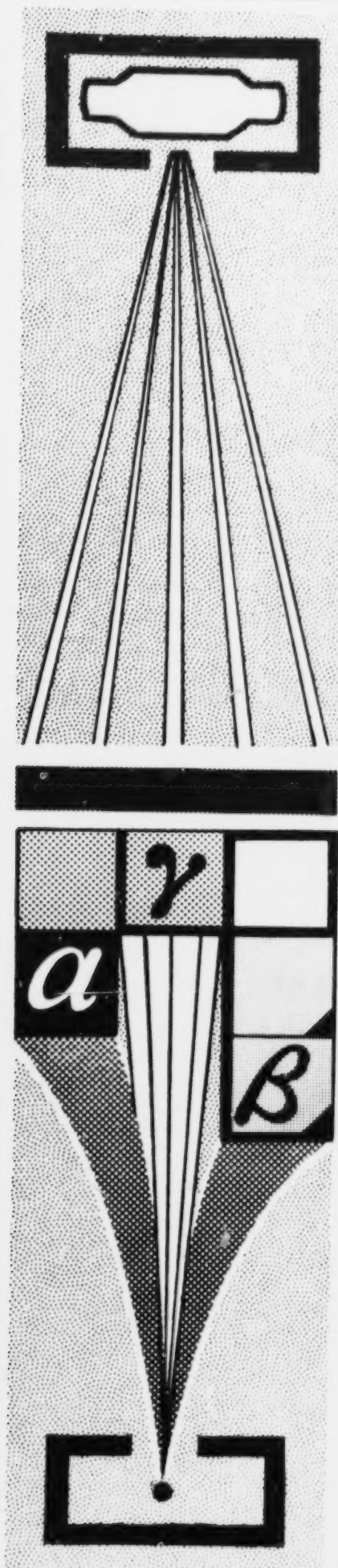


PB 184130

REPORT of the
TASK FORCE on X-RAY
IMAGE ANALYSIS and
SYSTEMS DEVELOPMENT



U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Consumer Protection and Environmental Health Service
Environmental Control Administration

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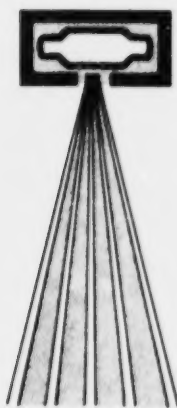
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DMRE 69-1	Report of the Task Force on X-ray Image Analysis and Systems Development

REPORT of the TASK FORCE on X-RAY IMAGE ANALYSIS and SYSTEMS DEVELOPMENT

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FOREWORD

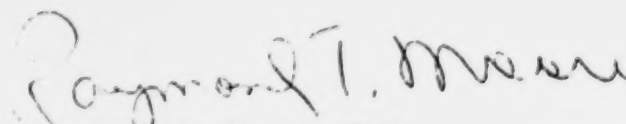
The Bureau of Radiological Health, formerly the National Center for Radiological Health, continues to carry out a national program designed to reduce the exposure of man to hazardous ionizing and non-ionizing radiation.

Within the Bureau, the Division of Medical Radiation Exposure deals with 1) the reduction of unproductive ionizing radiation exposure of patients, workers, and others exposed by the use of X-rays and other machine produced ionizing radiation, radioactive materials and radio-pharmaceuticals, and 2) the improvement of radiological "systems" and methodology in the healing arts.

The Bureau publishes its findings in Radiological Health Data and Reports (a monthly publication), the Environmental Health Series, Public Health Service numbered reports, appropriate scientific journals, and Division technical reports.

The technical reports of the Division of Medical Radiation Exposure (DMRE), formerly the Medical and Occupational Radiation Program (MORP), allow comprehensive and rapid publishing of the results of intramural and contractor projects. The reports are distributed to State and local radiological health program personnel, Bureau technical staff, Bureau advisory committee members, university radiation safety officers, libraries and information services, industry, hospitals, laboratories, schools, the press, and other interested individuals. These reports are also included in the collections of the Library of Congress and the Clearinghouse for Federal Scientific and Technical Information.

I encourage the readers of these reports to inform the Bureau of any omissions or errors. Your additional comments or requests for further information are also solicited.


Raymond T. Moore, M.D.
Acting Bureau Director

PREFACE

The April 1966 report of the National Advisory Committee on Radiation entitled "Protecting and Improving Health Through the Radiological Sciences" recommended, "...a series of applied research and development programs to increase the effectiveness and safety with which radiological procedures are employed in the health professions." In addition, the Presidential Message to Congress on health (February 28, 1967) called for new ways of providing medical services to the public. Systems analysis and automated techniques of examination and diagnosis, including the extensive use of radiographic equipment, were among the approaches suggested.

To implement these recommendations, a task force of outstanding experts in radiology, engineering, and computer science was formed under Public Health Service contract with the University of Missouri. This task force, under the direction of Dr. Gwilym S. Lodwick, Chairman of the Department of Radiology, was responsible for developing this comprehensive report on the present state of the art and the projected future for X-ray image analysis and automated systems development.



John C. Villforth
Chief, Division of Medical
Radiation Exposure

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ROSTER OF
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OBTAINING THE MAXIMUM BENEFIT
OF RADIATION EXPOSURE
IN DIAGNOSTIC RADIOLOGY
THROUGH IMPROVED PRODUCTION
AND UTILIZATION OF IMAGE FORMATION

SUMMARY AND RECOMMENDATIONS

This is the report of an NCRH Task Force on X-ray Image Analysis and Systems Design, which for a year has been studying the functional organization and status of diagnostic radiology from a perspective of increasing the effectiveness of radiological systems while obtaining the maximum amount of diagnostic benefit per unit of radiation exposure. The roster of the Task Force reflects the increasing complexity of the radiologic discipline now and for the future. Clinical radiology is represented by radiologists and radiological physicists with research experience in information systems and information management; science and industry are represented by physicists, electrical engineers, industrial engineers, hospital management experts, and computer specialists, all of whom have extensive experience with problems relating to diagnostic radiology. The Task Force is motivated by a common community of interests through its recognition of the pressing needs of clinical radiology, especially in its relationship to the vast problem of improving the health care of the nation.

The Task Force has regarded its mission as one of focusing its specialized knowledge upon the structure of diagnostic radiology in order to (a) broadly define the principal functional areas within the discipline, (b) to evaluate the state of the art in these functional areas, (c) to predict the probable future course of developments in these areas, (d) to identify goals of immediate significance, goals of longer range significance, and objectives where further investigation is either not warranted or offers little immediate or long range promise.

Quite early in its deliberations, the Task Force recognized that its consideration of diagnostic radiology must be made in the context of a number of serious problems relating to the delivery of health care; such as:

1. The rapidly increasing costs of providing health care for the Nation.
2. The serious deficit in the staffing of health care fields.
3. The rapidly increasing complexity of health care, relating largely to the exponential rate of increase of information, and to the resulting superspecialization in medicine.

In this context, it is obvious that in the face of an unprecedented demand for increase in volume and quality of health services, with no relative increase in production of those qualified to carry out health care, potential solutions for these problems lie principally in the area of increasing the efficiency of the system which delivers health care.

In diagnostic radiology, this system consists largely of the mechanisms for generating information in the form of a radiographic image, evaluating the image and delivering the translated image information into the hands of those who need it. (See flow chart, page xx).

To expedite considerations of these major functional areas, the Task Force has formed four working subcommittees, each charged with a specific objective. Accordingly, the recommendations in this report are presented under four classifications:

1. Operational Analysis
2. Image Information Generation
3. Image Information Evaluation
4. Image Information Delivery

Inasmuch as this evaluative program has been accomplished within the period of one year, there are limitations to the depth of the specific problem for which each subcommittee was responsible. Indeed, despite their esoteric knowledge in specific areas of investigation in radiology, subcommittee members at times found themselves reluctant to assign value judgements or to rank subjects for investigation. However, each of the recommendations which follow may be taken as the opinion of an informed and seriously concerned group of individuals which has carefully examined the area reported upon, and within the limitations of available time and information these recommendations reflect their best professional judgement.

The recommendations are as follows:

1. Operational Analysis Summary: A report on the current status of systems design and operational scheduling in radiology, with an evaluation of future goals and a recommendation of emphasis for support of future research in the analysis and implementation of radiological systems.
 - (a) There is a need for research into the determination of the important sources of demand for radiological procedures. This would include both those sources associated with the patient; i.e. variations in demand due to ethnic, socioeconomic and geographic distribution; and demand as generated by physicians due to suspected diagnosis and medical practice. It is felt that this might lead to a document that recommends when specific procedures should be requested.
 - (b) There is a need for research into the existing and potential managerial and organizational patterns of radiology departments as related to hospitals with a definitive statement of the roles and responsibilities of the radiology department and the hospital or hospitals involved. The objective of this research would be to determine the loss associated with the various non-optimum organizational patterns and demonstrate the need for improved training and knowledge in radiology for hospital administrators and managerial training for radiologists, and their delegated representatives when applicable.

- (c) There is a need for the development and demonstration of performance measurements which reflect the matching of resources to demands for a particular quality level. Such indicators should be of such form that they provide the same basis when comparing two or more radiology departments.
- (d) There is a need to demonstrate the use of existing techniques and the development of new managerial techniques to increase the effectiveness of the radiologic services; such techniques include but are not limited to: forecasting, planning and scheduling. Such techniques should optimize the use of currently available resources as well as the planning for future needs.

2. Image Information Generation Summary: A report on the components of image information generation, including x-ray generation equipment, positioning equipment, static and dynamic receptor systems, information presentation and basic information study. Recommendations include identification of critical areas of future needs.

- (a) As noted in the review of the current usage of radiological positioning equipment, little equipment is presently offered to the radiologist for highly specialized and automated use for a single examination or a small number of closely related examinations. A review of the different examinations made by radiographic means indicates that there are suitable candidates for highly standardized examinations that are routinely done in large numbers in many large institutions. It is recommended that the development of specialized apparatus in these instances be encouraged.
- (b) An examination of typical work loads in the medium and large sized hospitals shows that a relatively high percentage of the total radiographic work load can be associated with very specific examinations. Many of these examinations require relatively short times and have the capability of processing a large number of patients in a day's activity. It is recommended that the possibility of integrating, from an equipment standpoint, the making of the radiographic exposure with the identification of the film and the automatic processing of the film be explored for this class of examination.
- (c) A review of methods utilized in film sorting, filing, and retrieval in the larger departments of radiology indicates that a minimal degree of automation is presently employed. It is felt that significant benefits could be derived from the standpoint of economy and health care if a considerable degree of automation could be introduced into film sorting, filing and retrieval for the institutions requiring large film files.

(d) The method of generation of x-rays has remained essentially static for several decades. A variety of suggestions have been put forth from time to time for basic or fundamental alternates in x-ray sources. Technology has made considerable advances in the area of materials and basic understanding of the physical processes involved. It is recognized that any basic alternate in this area is highly speculative from the standpoint of possible success. However, since the characteristics of the x-ray source in terms of focal spot size, intensity, and exposure time are basic limitations in information generation for radiological purposes, it is felt that research should be encouraged in this area.

(e) Film-screen-processing system improvements:

A study of speed, quantum utilization and screen modulation transfer suggests a reasonably invariant domain of frequency response and quantum noise relationships within which radiographic systems can be designed around a particular film. It seems that desirable areas outside of this domain might be obtained by research on energy converters with anisotropic energy conversion. A well known example which can serve to illustrate this possibility is the possible usage of cellularized screens which have been reduced to practice only in the laboratory or in arrays of gross fibers for use in experiments in high energy physics.

(f) Currently the most widely used image intensifier system is the electron optical fluoroscopic image intensifier. There are a number of possibilities for research accomplishments leading to improvement of present electron optical image intensifier systems:

- 1) Improved quantum utilization
- 2) Improved electron optical noise figures
- 3) Improved resolution (modulation transfer function)
- 4) Alteration of conversion efficiency
- 5) Improved output spectral matching
- 6) Improved gamma
- 7) Improved contrast range

Research in these areas of possibility would lead to improvement in the major problem of current intensifiers i.e., noise, poor resolution and poor contrast.

(g) A most promising area for development in the field of information presentation is in the area of image transmission. Its importance derives from the shortage of professional radiologists and the possibility that the transmission of images from satellite operations to central reading areas would increase the efficiency of the radiologist. Also, the intra-hospital transmission of images has some value in teaching and in communication between the radiologist and the referring physician. Pilot studies also suggest the possibility of transmitting images over long distance telephone lines--a much slower but potentially cheaper system that might be of value in some applications.

(h) Well known concepts of communication theory should be applied to study the inherent capabilities and limitations of the radiological process as a whole. This will require knowledge of the primary input to the process which relates to the final output that is diagnostically important. The physical and psychophysical transfer characteristics essential for determining information transmission by each operation need to be identified and methods for their measurement developed.

- 1) Image Quality Related to Diagnostic Results.
Determine the relationship of observer response, which is the basis for diagnosis, to "image quality".
- 2) Image Quality Related to Physical Factors.
Correlate "image quality" with the physically measurable characteristics of the radiographic image which are meaningful to the system analyst and designer.
- 3) Elemental Analysis of Image Formation.
Develop a mathematical and physical conceptual module of the elemental and statistical process of image formation at the receptor to correlate the differential radiation absorption of the subject to the physically measurable characteristics of radiographic images.

3. Image Information Evaluation Summary: A report concerned with the development of information from the radiographic image, through various combinations of manual reading, image enhancement, manual or automated feature extraction, computer aided diagnosis, manually controlled image selection or automated scanning of radiographic images. The report presents a flow chart of these highly interrelated research areas, and indicates the relative position of each area in the development of the total problem.

A. Manual Interpretation: Recommendations: In order to further improve the manual interpretation of radiographs, it is recommended that:

- 1) Each radiologist employ visual aids such as reducing lens and high intensity illuminators in order to perceive unsharp, low contrast shadows.
- 2) Each radiologist should analyze his sources of error of perception in order to clarify and ultimately solve them.
- 3) Periodic visual acuity tests should become a part of periodic reexamination of radiologists
- 4) Research in the field of physiological optics, particularly relating to quantum and noise effects in human vision, should be encouraged and intensively supported.

B. Image Enhancement: Summary and recommendations:

- 1) There are three main types of image enhancement systems that can be used to process radiographic data.
 - a. Digital systems using film scanners and computers
 - b. Television-type systems
 - c. Optical systems
- 2) A particular enhancement procedure can be accomplished on all these systems. Each kind of system has its own particular advantages and disadvantages, depending upon the kind of enhancement operation employed.
- 3) Enhancement operations include the following: filtering, image subtraction, contrast enhancement, color translation, three dimensional reconstruction, and interpolation between motion picture frames.
- 4) Turn-around time, the time required to produce an enhanced image from the moment when its need is recognized, is now impractically long. Reduction of turn-around time can be accomplished by further research, which generally is of a very costly nature.
- 5) The enhancement of a radiographic image may be shown to be of value in a special circumstance. The total impact of image enhancement in the recognition and interpretation of disease in the clinical environment remains yet to be evaluated.

C. Manual Feature Extraction: Summary and recommendations

- 1) Computer aided diagnosis promises to provide a more definite and precise analysis of the information which is recorded in the radiographic image of disease. It will contribute to obtaining the maximum benefit per unit of radiation exposure by (a) minimizing diagnostic errors; (b) providing more efficient utilization of the radiologist's time; (c) improving the quality and availability of radiological health care to the nation, and (d) hopefully reducing the per unit cost of radiological services. Further (e) it will provide the logical data base for future development of automated analysis of radiographic image.
- 2) To become a clinically useful tool and a data base for the future, computer aided diagnosis needs to be expanded into all disease systems. This requires that integrated studies of all such systems be carried out, in which (a) accurate public models are defined; (b) precise incidence values for both normal and pathologic states are established and (c) a key reference source of case material is made available for analysis and testing of diagnostic systems.

- 3) In support of this research goal, the committee recommends the establishment of a Diagnostic Research Center, where residents in training, research trainees and practicing radiologists can learn about machine mediated diagnostic techniques; and where research in diagnostic techniques may be initiated.
- 4) In conjunction with the Diagnostic Research Center, it is recommended that the following mechanism be established to extend research already accomplished in computer aided diagnosis.
 - (a) Appoint a panel of radiologists (an expert for each organ system or diagnostic subdivision) with the responsibility of setting policy for research, establishing the diagnostic signs to be evaluated, and interrelating studies on public models.
 - (b) Appoint a panel of pathologists (one expert for each organ system or diagnostic subdivision) to establish positive histologic proof for each case to be evaluated, and to participate in the direction of the research program.
 - (c) Develop an effective technique for collecting research material from contributing institutions. Such cases must be well documented and proved histologically. Cases would be submitted to the panels for classification and analysis, and would comprise the data base upon which research on public models, statistical analysis, and computer techniques is conducted in the Diagnostic Research Center. Such material would be available to independent investigators, within the capability of the center to provide access to it.
 - (d) It is suggested that such a coordinated approach to research in computer aided methods of diagnosis is of sufficient importance to the future of radiological health care, that it should be under the sponsorship of national organizations interested in the improvement of health care, (for example, the USPHS, The American College of Radiology, and the American Cancer Society.)

D. Machine Aided Feature Extraction: Summary and recommendations

- 1) The combination of a light pen-like device, scanner and computer can provide great flexibility for quantitative measurement of radiographic images.
- 2) The use of the image segment selector mechanism and computer appears to be a logical next step on the road to complete automation of x-ray diagnosis. Research in this endeavor should be encouraged and supported where possible.

E. Automated Scanning: Summary and recommendations:

- 1) An automated scanning system is possible only if a systematic overall directed effort is made in obtaining a reliable data base (data accumulation), implementation of accurate measurement systems (film scanning systems), measurement selection techniques (roentgenographic signs selecting the measurements needed), decision schemes for classification (classifying to normal or abnormal, or into classes of diseases), and measures of performance (confidence level of the classification reached). In short, a considerable effort must first be made in several areas before a prediction is possible as to the practicability of an automatic scanning system. Such efforts will be rewarding of themselves in assisting the radiologist towards improving his skills; such efforts will be necessary before a formal judgement is rendered regarding the feasibility of the development of a practical automatic scanning system.
- 2) An automated x-ray scanning system is a goal towards which the radiologist should strive. Use of the digital computer offers the most likely tool towards accomplishing this goal. Extensive efforts are needed in developing both hardware interfaces and software programs for use with the digital computer before the goal of an automated scanning system is practical.

F. Image Information Delivery: Summary:

A report concerned with automated techniques of radiological reporting including off line techniques and on line interactive systems. The report includes recommendation of short and long range goals for the development of off line and on line systems.

Recommendations:

- 1) Immediately (for completion within a few years)
 - (a) Survey radiologists to determine their information needs and the forms that their information takes.
 - (b) Determine the state of the art of information systems in general and medicine in particular.
 - (c) Develop, test, evaluate and implement an off-line system based on the narrative approach.
 - (d) Continue development of existing prototype on-line systems.

2) Longer range

- (a) Expand existing narrative systems to on-line approach.
- (b) Select for further development the on-line interactive system that shows the best promise (including the concept that it will have been tested to see what its over all implications are in prototype use before it is widely implemented).

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OBTAINING THE MAXIMUM BENEFIT
OF RADIATION EXPOSURE
IN DIAGNOSTIC RADIOLOGY
THROUGH IMPROVED PRODUCTION
AND UTILIZATION OF IMAGE FORMATION

INTRODUCTION AND STATEMENT OF GOALS

In the face of an unprecedented increase in quality and availability of health services today, there are a number of unsolved problems which have created a crisis in American Medicine. These problems largely evolve around the fact that health care is no longer considered to be a service available only to those who can afford to pay, or to population groups for whom special provisions have been made. By contrast, good health today is regarded as the right of every citizen. As the result, there has been an unprecedented demand, so that available health care and training facilities have become overtaxed. If we are to attempt to care for our entire population with the same facilities which were formerly used to care for a portion thereof, major dislocations and difficulties are bound to occur.

Some of the unsolved problems may be identified as follows:

Firstly, the increasing costs in health care. During 1967 it would appear that there has been approximately a \$10.00 increase in the per diem cost of health care, now around \$60.00. This represents a 20% overall increase. While a part of this increase may be attributed to the offering of extended services and to inflation, a substantial portion can be attributed to better salary support for the large volume of hospital personnel who provide health care services at the paramedical levels. Adequate salary support of these groups has lagged to the point where, due to their low income, these personnel have in effect subsidized the costs of hospitalization. However, in recent years, there has been a steady improvement in the salary support of these groups to the point where their income is beginning to match those of comparable non-health care employees.

Secondly, there is a serious deficit in the staffing of health care fields, for a number of reasons. For instance, the training of physicians is a complex and expensive process, and the organization of the new medical school requires the development of vast levels of short and long range financial support, and further dilution of the already inadequate pool of teachers and researchers to carry out educational objectives. In the nursing and paramedical fields, where unprecedented numbers are being trained, the combination of low incomes, biology, and poor opportunities for career development continue to create an artificial scarcity. Low incomes and biology are interrelated. Salaries too low to support a family discourage the recruitment of males; the training positions are therefore filled

with females, most of whom marry and work only part time. In addition inadequate salary support has resulted in the loss of personnel into other better paid fields at a rate almost equal to the rate at which they are produced by training schools. However, even if there were a production of medical and paramedical personnel at a level equal to the rate of increase of our population, we would still fall behind because of the greatly increased rate of demand. For example, in the field of Radiology, the annual rate of increase of demand for a radiologist's time is estimated from 15 to 25%, based not only upon an overall increase in numbers of examinations, but also upon the complexity of the examinations requiring a greater expenditure of time. Under our present operating circumstances, the radiologist simply cannot continue to meet this increased level of demand and at the same time carry out other necessary functions, such as teaching and research.

Yet a third problem relates to the increase in complexity of health care. The rate of increase in knowledge today is such that what is known about a discipline doubles about every 8 years, although some of this rate of increase replaces older, now less useful information. Since there are limits to the capacity of an individual to learn more and more about a field, and since the length of time required to train a physician is already uncomfortable long, the impact of this rate of increase of knowledge is to motivate the physician to limit his scope of study in order to develop greater knowledge in depth about the subject. This is the definition of specialization. A practical example of this can again be observed in the field of radiology. In the post World War II era, nearly all radiologists were trained as generalists with major focus on both diagnosis and therapy. Even in the academic environment, the general radiologist very often accepted responsibility in more than one area, and may actually have rotated to different assignments. Since 1950, we have not only developed rather sharp lines of subspecialization between diagnosis and therapy, but several fields of subspecialization have grown up within diagnosis, such as pediatric radiology, neuroradiology, cardiovascular radiology, gastrointestinal radiology and nuclear radiology. The lines between subdisciplines are becoming increasingly sharp, and training and qualification for subspecialty groups are being emphasized. This strong motivation to learn more and more about less and less is based very simply on the fact that in the presence of our increasingly high standards, the physician cannot feel comfortable without such restrictions. A possible solution to this problem, rather than to further compartmentalize the kinds of information to be retained in the physician's memory, would be to make the great bulk of required information immediately accessible from some external source.

Medicine is faced then on one hand with an unprecedented demand for increase in volume and quality of health services, and on the other hand with no relative increase in production of those qualified to carry out health care. If we are to carry on as we are, we face an inevitable deterioration in the quality of available medical care.

What are some of the solutions to this problem?

- 1) To increase the numbers of qualified health specialists, by enlarging and increasing the numbers of training facilities. This is more easily said than done, because of the lack of qualified teaching personnel, and because the rate of increase of demand is greater than the rate of increase of population and of available students.
- 2) Within the structure of good medical practice, it must be possible for a physician to restrict his efforts sharply to those activities for which he is uniquely qualified. He should delegate less demanding or non professional functions to paramedical groups that have been intensively trained to handle limited and specific problems of health care and administration.
- 3) We must focus on the problem of reducing patient stay, since a reduction will conserve both patient money and physician time. To accomplish this, there must be a thorough re-evaluation of the hospital systems which have changed but little in pattern since hospitals were first conceived. The flow of patients through hospitals must be carefully analyzed and new patterns developed which will reduce the time required for diagnostic procedures and expedite the flow of information into the hands of those who need it.
- 4) We must develop new methods of transmitting, storing and retrieving information within the medical practice system. Information banks are needed to provide the physician ready access to vital information, to speed his ability to make decisions and permit him to narrow his memory efforts to principles and techniques of health care.
- 5) Screening techniques must be developed which can carry out automatic evaluation of laboratory data and successfully identify negative examinations and simple diagnoses, to relieve the physician of the burden of routine work and permit him to focus his special knowledge and capability on the challenging problems which require his attention.

In the past several decades, a number of disciplines have been developed around the requirements of business, science and industry for solving the problems similar to those described above which have affected their growth. The science of industrial engineering has had great impact upon the design and economy of the manufacturing industries where, for example, simulation studies have predicted the long range needs of plant design long in advance of funding and construction. A second major contribution has been the computer, which in business and industry has revolutionized information management. Because of its impact, growth of the computing industry has been phenomenal.

While business has used operations research and the new science of information management for streamlining its operations and making them more efficient, medicine has lagged badly behind in these efforts. It is only fair to point out that in health care, application of the principles of industrial engineering and information management are considerably more difficult than in industry. However, hospitals and universities have already made large investments in computers to assist in scientific computation and for business management, and computers are often available for pilot studies. At this time there are a number of large programs which are aimed at developing the degree of flexibility inherent in placing all medical and pertinent information about the patient in computer memory.

Among the disciplines which are based largely in hospital, radiology has already demonstrated leadership in the development of these new tools. At the present time there are now pilot studies under way to simulate the operation of the complex, large hospital department of radiology, to apply the principles of operation analysis to the function and future design of such departments and to explore the many avenues of information management. These ongoing studies represent only an optimistic beginning. There remains a vast amount to be done to remodel the environment of the department of radiology for health care, and to create high levels of effectiveness in management of diagnostic procedures, and to get the most diagnostic information per unit of radiation exposure. It is extremely important that such efforts be made, for radiology is a keystone in the diagnostic process.

That it is a keystone is evidenced by the fact that each year more than one-half of the population of the United States is medically examined by radiological techniques and that in many large hospitals, a number equal to the entire population of patients is examined during the period of a week. Another index of radiological usage is the consumption of x-ray film which increases at a rate of from 5% to 6% annually, or doubles every 13 years. This index does not begin to reflect the actual rate of increase of radiological service because as indicated above the time required for individual examination has sharply increased. One might presume that with such a monumental increase in demand for radiological services, and that with an unresolved problem of lack of supply at the source of training of radiological health specialists and paramedical personnel, that a training and research effort of comparable magnitude would be underway to resolve these weighty problems. But such is not the case. There is instead a real paucity of experimental research and research training in the academic departments of radiology throughout the United States. The meagerness of this research effort was cited in the April, 1966 report of the National Advisory Committee on Radiation⁽¹⁾ which indicates that in 1964 only \$1,700,000 was allocated by the Public Health Service to support pre and post doctoral training in academic departments of radiology, (including diagnostic radiology, radiotherapy, physics and nuclear medicine). This amounted to only 1% of all such training support for medical schools and other research institutions.

In the same year only \$528,000.00 was awarded for support of research in diagnostic radiology.⁽²⁾ The amount of traineeship support for diagnostic radiology has increased to the point that in 1966 more than \$1,000,000.00 was awarded to support research training in diagnostic radiology alone. This new support is administered largely through the Radiology Training Committee of the National Institute of General Medical Sciences. However, the number of research grants awarded directly to diagnostic radiology is still disappointingly small, probably less than \$1,000,000 from the United States Public Health Service,⁽²⁾ and certainly not of an order of magnitude necessary to support the comprehensive research efforts which must be carried out in order to solve the problems discussed above.

Aware of these tremendous problems which confront diagnostic radiology, the National Center for Radiological Health has expanded from supporting research in radiological health and the training of radiological health specialists to a much more comprehensive program of supporting: (1) research in systems design and analysis; (2) research in equipment design and utilization; (3) research in department design and (4) research in image analysis; all relative to getting the optimum benefit from diagnostic radiology. Further the NCRH has undertaken to support this study of information management in diagnostic radiology in order to obtain recommendations as to which areas need immediate and intensive investigation and which should be identified for longer range efforts. (NCRH Contract Number PH 86-67-198 X-ray Image Analysis and Systems Development).

The Task Force which has accepted this responsibility consists of nineteen specialists. Business, science, medicine and industry are represented. Each member has a unique perspective and experience in dealing with problems of diagnostic radiology. The technical fields represented include clinical radiology combined with research experience in information management and image analysis; hospital systems design; the physics of optics and image analysis; the engineering aspects of equipment design; the engineering aspects of image enhancement and analysis, and information systems design.

The Task Force held its first meeting at the National Center for Radiological Health on July 7th 1967. The goals for this first meeting were limited to orientation of the group and to the development of the approach that would be used in evaluating the need of diagnostic radiology. A flow chart was constructed to represent the dimensions of the problem in time space (Page xx) from which it became apparent that the problem could be divided into four sections:

1. Operational analysis
2. Image information generation
3. Information evaluation
4. Information delivery

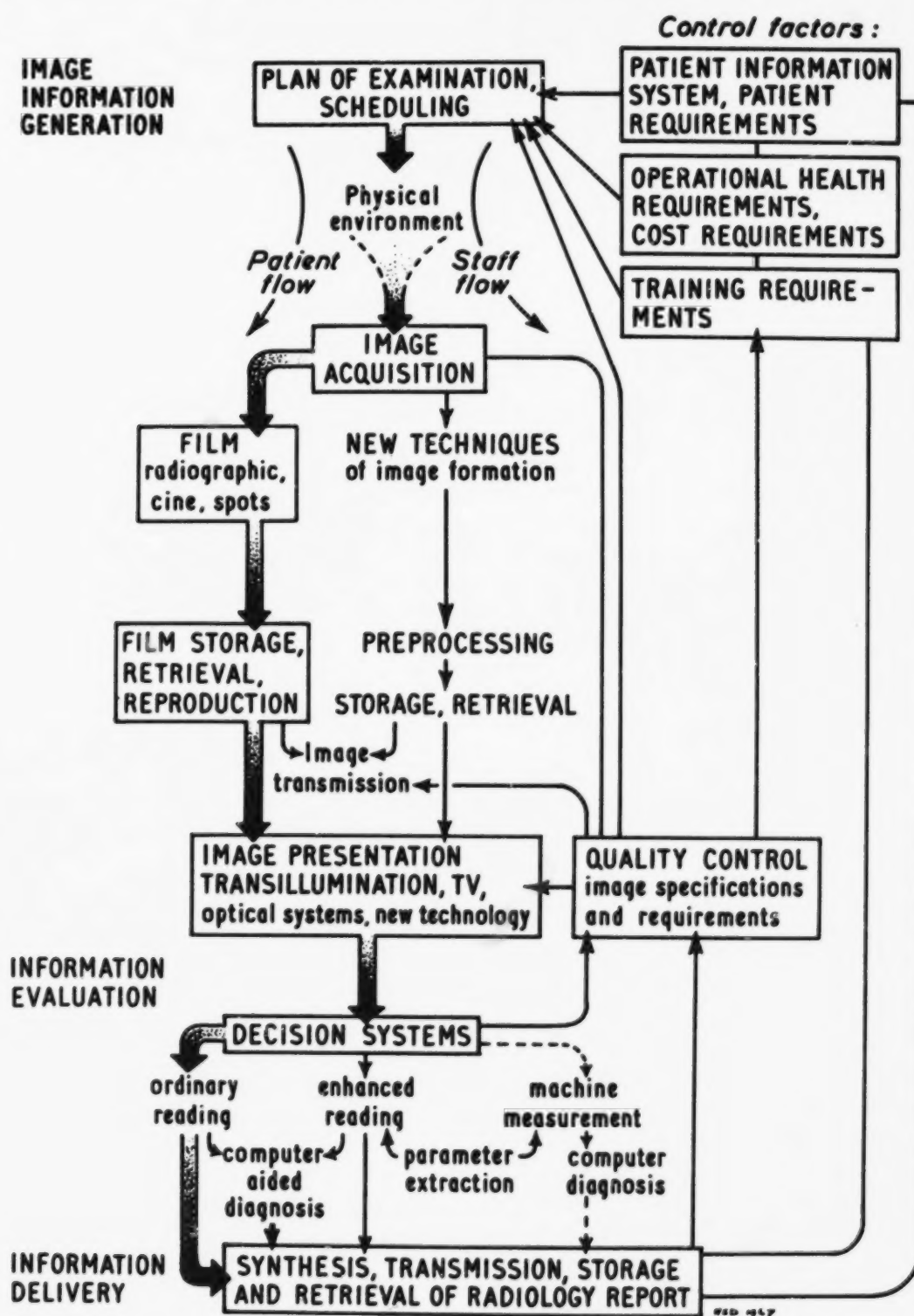
Subcommittees were appointed to study these four principal areas. In addition, it was agreed that a compendium of abstracts for pertinent literature would be prepared as a background of references for the report. A tentative deadline of July 1, 1968, was named for completion of the project. Additional meetings were held during the year where each subcommittee reported on its progress subject to the analysis and criticism of the entire Task Force.

Through the test of time, this plan proved to be an effective and appropriate division of effort for the study of diagnostic radiology. The structure of the final report follows the original plan. The individual reports and the subcommittees which prepared them are presented in the sections which follow.

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1. Protecting and improving health through the radiological sciences. The National Advisory Committee on Radiation, April, 1966.
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INFORMATION MANAGEMENT IN DIAGNOSTIC RADIOLOGY



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SECTION I

OPERATIONAL ANALYSIS

Summary: A report on the current status of systems design and operational scheduling in radiology, with an evaluation of future goals and a recommendation of emphasis for support of future research in the analysis and implementation of radiological systems.

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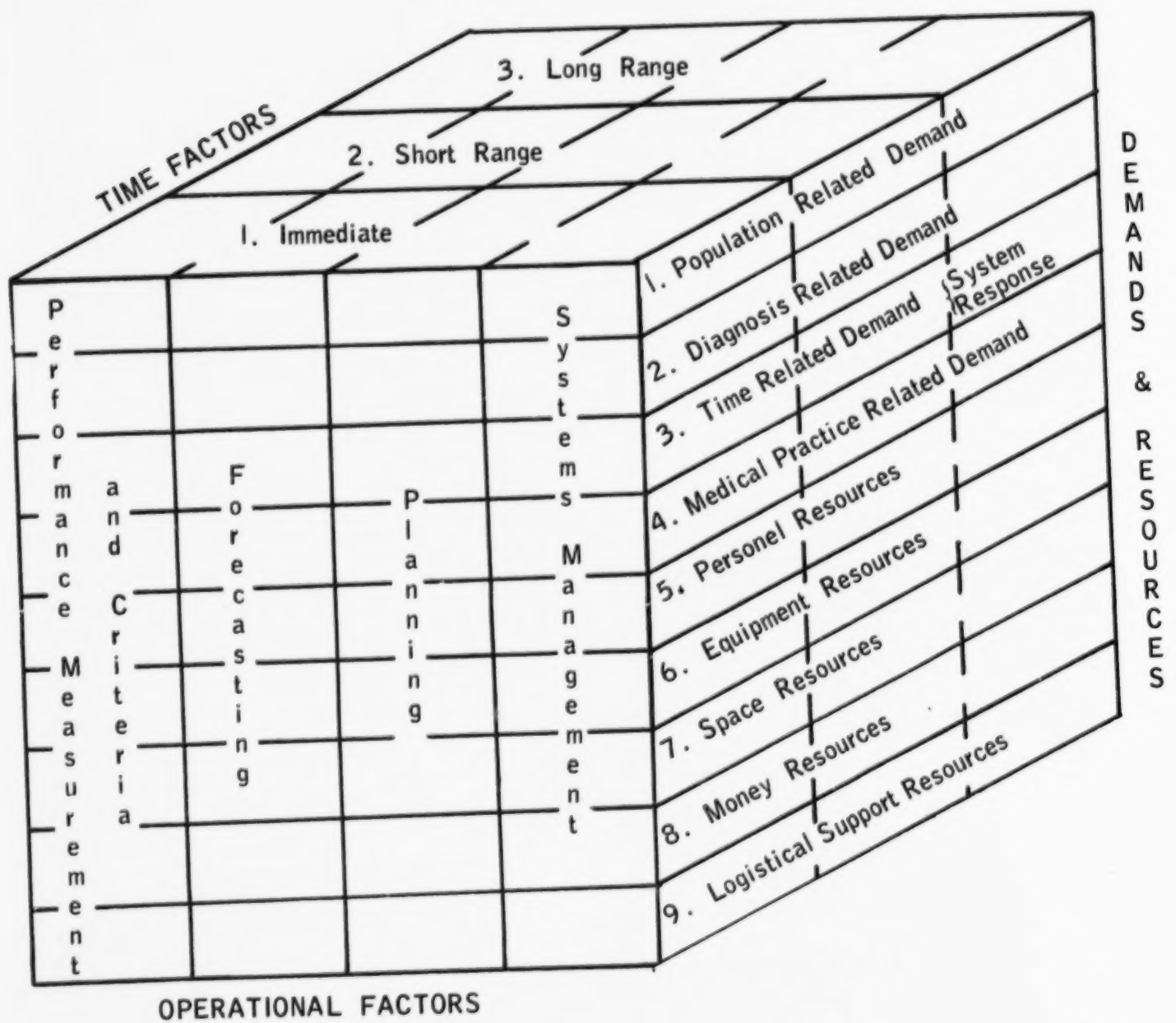
INTRODUCTION AND CONCLUSIONS

The Operational Analysis Committee was to determine the need for research into the operational aspects of diagnostic radiology departments. The committee has viewed the radiology department as a part of the total health care system. In part this was necessary, since the radiology department is part of the larger health care system and interacts with it continuously. This interaction requires an examination of those facets of operation that are part of other departments; both to improve the radiology system aspects of the interaction, and to take advantage of ideas and research in these other areas that might directly or indirectly benefit the operation of diagnostic radiology departments. The committee developed an a priori classification system of sufficient detail that it might be expected that the numbers of articles in each classification would be indicative of the research in that area. This system indicated that the largest area of need within the Operational Analysis Committee's scope was determination of the source of demand on a diagnostic radiology department. The other areas included managerial concepts and procedures, criteria of operation and techniques to increase effectiveness. The committee recommends the following areas as having potential benefits to the nation through research into the health care system, and specifically diagnostic radiology departments within the setting of a hospital.

1. There is a need for research into the determination of the important sources of demand for radiological procedures. This would include both those sources associated with the patient; i.e. variations in demand due to ethnic, socioeconomic and geographic distribution; and demand as generated by physicians due to suspected diagnosis and medical practice. It is felt that this might lead to a document that recommends when specific procedures should be requested.
2. There is a need for research into the existing and potential managerial and organizational patterns of radiology departments as related to hospitals with a definitive statement of the roles and responsibilities of the radiology department and the hospital or hospitals involved. The objective of this research would be to determine the loss associated with the various non-optimum organizational patterns and demonstrate the need for improved training and knowledge in radiology for hospital administrators, managerial training for radiologists, and their delegated representatives when applicable.
3. There is a need for the development and demonstration of performance measurements which reflect the matching of resources to demands for a particular quality level. Such indicators should be of such form that they provide the same basis when comparing two or more radiology departments.
4. There is a need to demonstrate the use of existing techniques and the development of new managerial techniques to

increase the effectiveness of the radiologic services; such techniques include but are not limited to: forecasting, planning and scheduling. Such techniques should optimize the use of currently available resources as well as the planning for future needs.

FIGURE 1. THE THREE DIMENSIONAL GRID



METHODOLOGY DEVELOPMENT OF SEARCH FRAMEWORK

Initial discussions of where research might be required indicated need for a systematic search of the broad area of health care service to determine the present state of the art. The recent explosion of literature in the health care field required that a means of classifying the literature to be essential. Several classifications exist, but are too broad to be of value. The classifications selected required that each article be assigned into each of three areas:

1. The operational factors involved;
2. The decisional time domain; and
3. Whether related to a demand on the system or a resource of the system.

It was recognized that a given publication might be such that it would need as much as one or more triple classifications.

Each type of classification was sub-divided into appropriate units. Thus the framework can be compared to a three dimensional matrix or grid, in which each triple classification represents a cell in the structure. The dimensions (types of classifications) were named:

1. Operational factors
2. Demands on, and resources of, the system
3. The time between a decision and its implementation

The three dimensional grid, with dimensional units expressed, is shown in Figure 1. The definitions and explanations of the dimensions and their units follow.

DESCRIPTION OF DIMENSIONS

OPERATIONAL FACTORS

Operational factors are those activities which might be carried on by a system manager. Four units or categories were defined as follows:

1. Performance measurement and criteria

Operational performance and/or criteria of the system is/are measured and/or established.

The operation of any system cannot be optimized without the development of standards of performance and operational criteria. These standards and criteria may be established for the radiology department as an entity, as a subordinate unit of a specific institution, or as a subordinate unit of the overall health care system. We wish to identify the measurement and criteria that have been quantified and reported, not evaluate the quality of the measurements and criteria.

2. Forecasting

Either performance, criteria or both of the system and/or the trends of the system is/are predicted.

Part of any manager's responsibility is to anticipate the needs and demands on his portion of the system. The further into the future that he can anticipate, the more effective he is likely to be. Statistical techniques are generally available to provide procedures for forecasting, if the correct variables can be determined.

3. Plannin

The design of the system is developed either intuitively or scientifically.

As is true of many other operational aspects of an organization, planning takes place; either willfully, or by default. The committee was particularly interested in the process by which planning was carried out including both the development of planning steps, and the use of computers to aid in the various aspects of the planning sequence.

4. System management (computer aided)

Operational management of the system through maintaining control of the demand/resource balance.

The manager is also charged with the responsibility of providing the service demanded on his organization. Sometimes this is met by changing the number of employees, or by expansion or contraction of the physical plant. Variation in work hours is also possible. Under some circumstances the manager can limit the demands for service by the use of finite schedules, or by increasing the cost of the service. Another possibility is the use of the pre-testing to eliminate certain classes of potential users.

It should be noted that the performance measurement improves the ability to forecast and that forecasting is a tool of planning. Performance measurement is also the basic tool of the manager in knowing what demands the organization can successfully meet.

DEMANDS ON AND RESOURCES OF THE SYSTEM

The committee selected nine categories of demands and resources:

1. Population related demands

The entry of specific groups into the system. The socio-economic environment of a group may be considered as one of the factors.

In essence, this demand relates to whether specific groups (geographical, ethnic, economic, or other) create specific problems for a radiology department. A population of tree-climbers, for example, might show a higher need for orthopedic radiology than a population of beachcombers. The knowledge of this demand should influence the design of the radiology department.

2. Diagnosis related demand

The radiographic procedures as demanded by specific diagnosis.

Certain diagnosis generate certain demands for radiographic services. Are these demands fixed, or are they changing? If so, how are they changing?

3. Time related demand

The availability of the patient, and the operational patterns and procedures as they affect the time-oriented demands on the department.

The time-related demands on the department frequently are not totally within the control of the department. For example, hospitals requiring a chest procedure for all new patients may create a considerable load during the normal admission hours. The need for special preparations and diets for certain procedures and the demands of current medical practice, such as the scheduling of all surgery in the mornings, creates periods of peak demand. The investigation of the effects of changing the time relation of the patient and department would fall in this category.

4. Medical practice related demand

The routines of accepted medical practice that are not specifically related to a given diagnosis.

This classification was designed to include those procedures that are routinely requested to a general medical practice, but without specific relation to an inferred diagnosis.

5. Personnel resources

Medical, allied health, and administrative personnel

6. Equipment as a resource

Both major and minor equipment in a radiology department

7. Space as a resource

8. Money resources

9. Logistic support as a resource

10. Symbiotic systems relationships

Interdependent demand/resource relationships of the healthcare systems or sub-systems

The resources do not seem to need further explanation in the same manner as the demands, so no more detailed explanations are included.

TIME-RELATION TO DECISIONS

The time factors dimension relates to the period available to make a decision and the time delay between a decision and its implementation. Some decisions are related to the day by day operation of the department, and decisions must be made in the immediate, or "today" sense. Other decisions are related to events further removed in time from the decision itself, and therefore are subject to different approaches. The three time periods used are:

1. Immediate

That time period in which the decisions apply to situations as they occur. Studies in this area will pertain to improvements in the usage of the equipment and personnel in which the usage immediately follows the decision made.

2. Short range

That time period in which decisions are made which modify existing practices, but do not make significant changes in the demands and resources. This could include a system for handling "future" scheduling and similar situations.

3. Long range

That time period in which decisions can have optimum effects on the levels of demand and resources available.

ASSIGNMENT OF PUBLISHED MATERIALS

The grid was used by assigning to each publication, or abstract of the publication read, at least one triple-classification. Thus an article might be considered to relate to Planning/Equipment/Long-range if it dealt with methods of selection of new radiographic equipment. If a publication provided criteria for operation, and then used these criteria in forecasting and planning, the publication would appear in at least three triple-classifications.

The initial review of the available sources of literature confirmed that the publications of operational analysis techniques and results in health care have expanded greatly in the last few years. Although relatively little work has been done directly in radiology departments, there have been many studies of entire health care systems, of which radiology departments are a part. Further, the publications within the health care field are presently being abstracted by the cooperative information center for Hospital Management Studies at the University of Michigan under the title: Abstracts of Hospital Management Studies. It was therefore decided to use these abstracts, and other annotated bibliographies as the basis of the literature search. Where the publications were available, and the members of the committee were not familiar with the publication, copies were obtained and read. Unfortunately, there remained a large number of research publications that were available only through University Microfilms, Inc. and from various university libraries. The one year limitation on the life of the task group prevented collecting and reading these documents, and they were judged on the basis of the prepared abstract.

The articles were assigned to the cells of the grid by mutual selection of the committee. The result, expressed as a series of two-dimensional tables, shows the number of publications which were assigned to each cell. These are shown in Table 1. (See Page 10)

Each cell was then examined in light of the number of publications and the committee acknowledged to decide whether the area described in the cell should be further researched or not. The categories used are:

1. There is no need for investment of funds as the field appears to be adequately covered.
2. The knowledge for improvements is available, but has not been applied. This area may have payoff through wider dissemination of the information that is available. An example of this would be information on performance measurements and criteria which have been worked out but which are not widely known.
3. Short-term research is needed in which the benefits of a minimum amount of effort are known.
4. There is a need for long-term research in which the benefits are not known; in which there are technical deficiencies; or in which a major effort might be needed to arrive at any benefit. Nevertheless, in all of these cases, there are questions that need to be answered.

Table 2 contains the assignment of the cells to the four areas of resource need indicated.

Measurement & Criteria	Forecasting										Systems Management									
	Symbiotics related	Logistics related	Money related	Space related	Equipment related	Personnel related	Medical practice related	Time related	Diagnosis related	Population related	Symbiotic related	Logistics related	Money related	Space related	Equipment related	Personnel related	Medical practice related	Time related	Diagnosis related	Population related
Immediate	3	2	0	1	0	1	1	0	1	1	29	34	3	12	15	35	8	10	7	8
Short range	3	1	0	2	1	1	1	0	0	0	10	10	0	1	1	9	0	1	0	0
Long range	11	2	0	4	4	3	3	1	10	4	11	4	0	0	1	1	0	1	0	0
Planning																				
Immediate	31	36	3	6	13	20	1	1	1	2	10	13	1	9	9	7	0	0	0	0
Short range	4	7	0	0	0	0	0	0	0	0	4	1	0	2	1	1	0	1	0	0
Long range	1	10	0	1	1	0	0	0	0	0	36	5	0	10	11	6	0	1	0	1

TABLE 1 ARTICLES AND REPORTS BY CLASSIFICATIONS

TABLE 2

1. Measurement & Criteria

		No. of References	No action needed	Education	Short term Research	Long term Research
1.1.1	Population related, Immediate	8			X	
1.1.2	Short range	0			X	
1.1.3	Long range	0				X
1.2.1	Diagnostic related, Immediate	7			X	
1.2.2	Short range	0			X	
1.2.3	Long range	0				X
1.3.1	Time related, Immediate	10		X	X	
1.3.2	Short range	1			X	
1.3.3	Long range	1			X	X
1.4.1	Medical Practice related, Immediate	8		X	X	
1.4.2	Short range	0			X	
1.4.3	Long range	0			X	X
1.5.1	Personnel, Immediate	35		X	X	
1.5.2	Short range	9		X	X	
1.5.3	Long range	1		X	X	
1.6.1	Equipment, Immediate	15		X	X	
1.6.2	Short range	1		X	X	
1.6.3	Long range	1		X	X	
1.7.1	Space, Immediate	12		X	X	
1.7.2	Short range	1		X	X	
1.7.3	Long range	0		X	X	
1.8.1	Money, Immediate	3			X	
1.8.2	Short range	0			X	
1.8.3	Long range	0				X
1.9.1	Logistic Support, Immediate	35	X			
1.9.2	Short range	10	X			
1.9.3	Long range	4			X	
1.10.1	Symbiotic, Immediate	29	X	X		
1.10.2	Short range	10	X	X		
1.10.3	Long range	11		X		

2. Forecasting

			No. of References	No action needed	Education	Short term Research	Long term Research	Comments
2.1.1	Population related	Immediate	1	X				
2.1.2		Short range	0				X	
2.1.3		Long range	4				X	
2.2.1	Diagnostic related	Immediate	1	X				
2.2.2		Short range	0				X	
2.2.3		Long range	10				X	
2.3.1	Time related	Immediate	0	X				
2.3.2		Short range	0			X	X	
2.3.3		Long term	1				X	
2.4.1	Medical Practice related	Immediate	1	X				
2.4.2		Short range	1				X	
2.4.3		Long range	3				X	
2.5.1	Personnel	Immediate	1	X				
2.5.2		Short range	1				X	
2.5.3		Long range	3				X	
2.6.1	Equipment	Immediate	0	X				
2.6.2		Short range	1	X				
2.6.3		Long range	4				X	
2.7.1	Space	Immediate	1	X				
2.7.2		Short range	2	X				
2.7.3		Long range	4				X	
2.8.1	Money	Immediate	0	X				
2.8.2		Short range	0				X	
2.8.3		Long range	0				X	
2.9.1	Logistic Support	Immediate	2		X			
2.9.2		Short range	1				X	
2.9.3		Long range	2				X	
2.10.1	Symbiotic	Immediate	3	X				
2.10.2		Short range	3				X	
2.10.3		Long range	11				X	

3. Planning

			No. of References	No action needed	Education	Short term Research	Long term Research	Comments
3.1.1	Population related	Immediate	0			X	X	
3.1.2		Short range	0			X	X	
3.1.3		Long range	1			X	X	
3.2.1	Diagnostic related	Immediate	0			X	X	
3.2.2		Short range	0			X	X	
3.2.3		Long range	0			X	X	
3.3.1	Time related	Immediate	0			X	X	
3.3.2		Short range	1			X	X	
3.3.3		Long range	1			X	X	
3.4.1	Medical Practice related	Immediate	0			X	X	
3.4.2		Short range	0			X	X	
3.4.3		Long range	0			X	X	
3.5.1	Personnel	Immediate	7		X			
3.5.2		Short range	1			X		
3.5.3		Long range	6		X			
3.6.1	Equipment	Immediate	9		X			
3.6.2		Short Range	1			X		
3.6.3		Long range	11		X		X	
3.7.1	Space	Immediate	9		X			
3.7.2		Short range	2			X		
3.7.3		Long range	10		X		X	
3.8.1	Money	Immediate	1				X	
3.8.2		Short range	0				X	
3.8.3		Long range	0				X	
3.9.1	Logistic Support	Immediate	13		X	X		
3.9.2		Short range	1			X		
3.9.3		Long range	5		X	X		
3.10.1	Sybiotic	Immediate	10		X			
3.10.2		Short range	4			X		
3.10.3		Long range	36		X			

4. Systems Management

			No. of References	No action needed	Education	Short term Research	Long term Research	Comments
4.1.1	Population related	Immediate	2			X		
4.1.2		Short range	0			X		
4.1.3		Long term	0			X		
4.2.1	Diagnostic related	Immediate	1			X		
4.2.2		Short range	0			X		
4.2.3		Long term	0			X		
4.3.1	Time related	Immediate	1			X		
4.3.2		Short range	0			X		
4.3.3		Long range	0			X		
4.4.1	Medical Practice related	Immediate	1			X		
4.4.2		Short range	0			X		
4.4.3		Long range	0			X		
4.5.1	Personnel	Immediate	20		X	X		
4.5.2		Short range	0			X		
4.5.3		Long range	0			X		
4.6.1	Equipment	Immediate	13		X	X		
4.6.2		Short range	0			X		
4.6.3		Long range	1			X		
4.7.1	Space	Immediate	6	X	X			
4.7.2		Short range	0			X		
4.7.3		Long range	1			X		
4.8.1	Money	Immediate	3			X		
4.8.2		Short range	0			X		
4.8.3		Long range	0			X		
4.9.1	Logistic	Immediate	36		X	X		
4.9.2		Short range	7			X		
4.9.3		Long range	10		X			
4.10.1	Symbiotic	Immediate	31		X			
4.10.2		Short range	0			X		
4.10.3		Long range	1			X		

RECOMMENDATIONS

Several areas appear to have outstanding needs at this time:

1. A development of the sources of demand for radiological procedures for predictive purposes.
2. The management of the radiology function.
3. The development of performance measurement standards that can be applied to more than one diagnostic radiology department.
4. The development of techniques for management actions.

1. A Development of the Sources of Demand for Radiological Procedures for Predictive Purposes.

Although a number of publications have described the relation of a specific area to its total health care systems, there are no separate publications that provide this same information for the use of radiology departments have extended the present usage based on the historical gross rate of growth. In essence, it is not known whether the changing demand for radiographic procedures results from a changing population, advances in medical sciences, a changing reliance on radiographic procedures, changes in the sophistication of radiological procedures, or some combination of these. Specific age groups, income groups, or ethnic groups may require different quantities and types of radiographic procedures, but no study of these variables has been noted. Further, there is presently no information about why specific physicians request specific procedures, either with respect to suspected diseases or as a general examination procedure. There would appear to be a need to develop guidelines and criteria as to when specific procedures should be requested, and the time sequence of follow-up procedures, when necessary.

Recommendation:

There is need for research into the determination of what are the important sources of demand for radiological procedures. This would include both those sources associated with the patient; i.e. variations in demand due to ethnic, socio-economic and geographic distribution; and demand as generated by physicians due to suspected diagnosis and medical practice. It is felt that the latter might lead to a document that recommends when specific procedures should be requested.

2. The Management of the Radiology Function

I. Introduction

Much is being said these days about the failure of the health system to take unto itself the critical challenge of devising new and improved methods of delivering health care to those who need it, at a cost that is reasonable, and in a manner that recognizes that the patient is to be respected as an equal member of the human race. This challenge has been given many names by many people. In this document, it will be referred to as the management of the health delivery system; and the challenge shall be viewed within an extremely narrow context, that being the management of but one function within the broader system. Many of the assumptions, conclusions, and recommendations contained herein apply equally to many other functions within the health delivery system. But, since the concern of this project is the radiology function, this report shall be limited to a critique of the management of this function only.

II. Statement of Basic Assumption

That there exists a rather critical problem in the management of radiological facilities that detracts from the optimum utilization of available health resources. Further, that this situation is reflected in high costs and inconvenience to the patient.

III. Context and Background

There is substantial evidence to support the assumption that in recent years the separation of the radiological system from the hospital as an organizational and functional totality has been widening. And, there is little evidence of any activity aimed at either evaluating or improving this situation. The literature contains many examples of work that have been undertaken which rather clearly exemplifies this condition. Examples include:

- (1) The development of scheduling routines oriented to maximizing the utilization of the radiology department, but having no relationship to the utilization of any other functional resources or to the comfort and convenience of the patient.
- (2) The implementation of record keeping procedures in the radiology department that bear no relationship to any other record keeping function in the hospital. This includes numbering schemes, filing techniques, billing systems, and reporting procedures.

- (3) The design and implementation of computer systems whose only function is to serve limited needs in the radiology department.
- (4) The construction and equipping of facilities based on the planning that took into account only building codes and operational considerations of the radiologic function.

It is difficult to determine when or for what particular reason this separation became essentially a traditional mode of operation. The provision of radiologic diagnosis is certainly a medical function and one that is in direct support of the diagnostic and therapeutic regimen that is the responsibility of another physician. Though the cause of separation is not especially clear, it is appropriate to this paper to at least briefly examine several contributing factors.

(a) Hospital Management

While the "chicken and egg" question may be apropos, this report will deal first with the factors emanating from the general management or administration of the hospital. As measured solely by a review of the literature, hospital managers have yet to comprehend the need to evaluate or to manage their institutions as highly integrated systems dedicated to common goals and objectives. The education and training of administrators has, with few exceptions, excluded exposure to even the basic principles of systems engineering, integrated business planning, etc. In day-to-day practice, hospital managers have continued the traditional pattern of exercising at most a rather casual relationship with the operation and management of the radiology department. Primary concern centers around the dollar surplus generated by the department, not on its costs, its integration into the operations of the institution, or its concern for the comfort or convenience of the patient.

The recent dispute over the rendering of bills for professional vs. hospital services has further widened the breach between hospital and radiology department operations.

In the face of this condition, there is mounting pressure from government, third-party agencies, and the public to stem the tide of rising health costs, to better coordinate the availability of health services, and to shift the focus of attention from the producer to the consumer.

The hospital manager of the future will need to become better prepared in the important disciplines which positively affect the inter-relationships of hospital based departments and, with the radiologist, develop a better understanding of which kinds of decisions affecting radiology departmental operations can best be made by the radiologist administrator and which can best be made by the hospital administrator.

(b) The Radiologist

In the hospital department of radiology, a physician, trained in his particularly specialty of medicine, is the primary (and/or sole) manager of a key component of the institution. His jurisdiction encompasses much more than the professional standards and practices of his component. With rare exception he is untrained in management techniques, systems engineering, architecture; all areas in which the radiologist currently exercises his authority.

Faced with this situation, the radiologist must become better informed about hospital managerial principles and become committed to the functional integration of the radiology department with other important hospital functions in the interests of improving the care of the patient, while not adding to his economic burden.

IV. Conclusions

The existing managerial gap between administration and the radiologist precludes the proper utilization of those systems, procedures, and techniques which might optimize the demand resources balance. Until we recognize that each and every functional component is but a subsystem within a larger system, we cannot significantly improve the current situation.

It is even possible to conclude that the continued development of intra-functional procedures will create a widening of the existing gap, unless we resolve the current failure of communication by a mutual orientation of management and radiology. This orientation will make it possible to reduce the roadblocks that make it increasingly difficult to develop and to implement new techniques for measuring, forecasting, controlling, and managing the resources and demands within the health delivery system.

V. Recommendation

There is a need for research into the existing and potential managerial and organizational patterns of radiology departments as related to hospitals with a definitive statement of the roles and responsibilities of the radiology department and the hospital or hospitals involved. The objective of this research would be to determine the loss associated with the various nonoptimum organizational patterns and demonstrate the need for improved training and knowledge in radiology for hospital administrators and managerial training for radiologists and/or their delegated representatives.

3. The Development of Performance Measurement Standards That Can Be Applied to More Than One Diagnostic Radiology Department.

A performance measure is simply a measure of how one's performance achieves its goals. A performance measurement standard attempts to provide a quantitative measure of the goals.

In many situations, the connotation of a standard implies an effort to restrict one's performance. However, in this discussion, the standard should be thought of as an objective basis for radiologists to discuss and compare their operations.

The need for performance measurement standards is based on several premises:

- a) any activity can be improved;
- b) more improvements in performance result by learning from colleagues than through any other source;
- c) the problem of translating improvements from one hospital (or radiology department) to another is establishing the same base.

To establish performance measurement standards, the first step is to establish quantitative objectives. This in itself is not an easy task. One objective, for example, is probably to provide the best service possible. This is a qualitative objective, but difficult to measure. What does best mean and what does possible mean? Best probably has many dimensions. Volume and time are at least two. Volume is a measure of number of patients, types of examinations, the amount of information provided, etc. Time is a measure of how soon can the patient be examined, how soon can the results be reported, etc. Possible indicates some constraint exists; such measures generally relate to resources: personnel, equipment, exam rooms, dollars, etc.

Given, that the first step is accomplished, the next step is to arrive at output descriptors (in some standardized terminology). In general, this falls out of the first step.

Now at this point, we should note that we are not saying that all radiology departments have the same goals or objectives. What does occur is that most departments have the same processes that take place and the same output measures can be used. The difference is the measures of the output.

The third step in developing performance standards is to provide numerical values. This is a measurement problem that may use many techniques such as counting, sampling, time study, etc.

The final step is to use the performance standards to control the performance of the activities that take place. This is an important step in development because it tests the standards established and results in refinement and identification of new measures required.

The literature reports little work in the development of performance standards. One of the task force members (Bartscht) has developed performance standards for the nonprofessional staff members of the radiology department. Little has been done to look at the over-all operations and provide some indicators of not only existing performance but ways to make improvements.

Some discussions have been concerned with the development of mathematical models (simulations) of the radiology function to plan new facilities, improve existing operations and control operations. None of this work will be very successful unless performance standards are established.

Again it should be noted, that a perfect set of output measures is not needed to start. In fact, the measures will continually get better, but no progress can be made until a start is made.

Recommendations:

1. Some goals of the radiology function should be described.
2. Output measures for these goals should be described.
3. A group of radiologists should participate in a study that would result in measures of these outputs for each of their departments.
4. The above group should then report these measures on a periodic basis and discuss the use of these measures and the strengths and weaknesses of these measures.
5. The result of the study would be a system of reporting performance measures and a basis for making comparisons.

4. The Development of Techniques For Management Actions

The previous recommendations necessarily touch on management techniques. This final recommendation is to describe other such techniques that can be used to more effectively manage the radiology function.

Given, that the radiologist has the results of the three previous recommendations: a description and measure of demands, an effective management structure, and performance measurement problems, the obvious question may be, what does one do with all this information? In general one plans, operates and follows-up.

Planning involves formulation of goals, forecasting demands and determination of future requested resources. The forecasting problem is not one of a lack of technique, but a lack of information and in turn, a lack of application of the technique. It is apparent that the application of more sophisticated forecasting techniques must be used if one is to insure that the increased resources required for the increasing demand will be provided.

The operating problem is one of trying to match resources with the demand. Scheduling techniques (including both patients and resources) can be employed to alleviate some of the operating problems. Again techniques are available, but few have been applied in radiology departments, and none have resulted in a methodology that can be applied generally to many hospitals. One difficulty, is its interactive effect between the radiology function and the rest of the hospital. Thus, any scheduling system must take into account these interactions.

The final activity is that of follow-up or the after-the-fact evaluation. The particular technique of interest would be one of quality control. This in general, is of a continuing sampling study that provides feedback to the department manager.

Recommendation:

Studies should be initiated that result in developing methodologies for use in:

- a) planning the expansion of departments, both existing and new facilities.
- b) scheduling all of the resources and the patient load to provide an optimal matching of each.
- c) control systems which insure that the department is meeting its goals and objectives.

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SECTION II

IMAGE INFORMATION GENERATION

Summary: A report on the components of image information generation, including x-ray generation equipment, positioning equipment, static and dynamic receptor systems,* information presentation, and basic information studies. Recommendations include identification of critical areas of future needs.

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2.0 IMAGE INFORMATION GENERATION

2.1 SCOPE

The scope of the Image Information Generation portion of this report includes the subjects of x-ray generation, the wide variety of positioning equipment associated with x-ray examinations, static and dynamic image receptor systems, the logistics and handling of the recorded image and the presentation of the recorded images for diagnostic evaluation.

Since this definition of scope includes most of the equipment and activities relating to the present conduct of radiological examinations, it is clear that the items discussed in this section must be selective and consistent with the goals set for the Task Group. Therefore, this broad subject matter will be considered only as related to potential advances in the state-of-the-art in the designated areas of image analysis and system design. This includes factors related to x-ray image quality; factors related to system design, especially the aspects of automation or other improvements less demanding on the limited quantity of radiological personnel; and other factors of the techniques of image acquisition that become important in the considerations of the Task Group.

The scope of this section on image information generation is limited to that of diagnostic radiology and does not include the consideration of diagnostic nuclear medicine, ultrasonography, thermography, radiation therapy and x-ray examinations related to radiation therapy planning.

As indicated in the introduction to this report, the purpose of this study is to determine the current status of certain aspects of diagnostic radiology, particularly with respect to the possibilities of areas of improvement of patient care, including the consideration of the least amount of radiation exposure commensurate with the diagnostic results, and to make suggestions as to areas where these improvements can be encouraged with the prospect of providing either short term or long term benefits. Included in the benefits specifically considered in the conclusions are reduction in radiation dosage, improvement of image quality, improvement of radiological department efficiency, and economy of radiological department operations.

In organizing the material in this section, the following subdivisions have been adopted:

- 2.2 X-ray generation equipment
- 2.3 Positioning equipment
- 2.4 Static receptor systems
- 2.5 Dynamic receptor systems
- 2.6 Information presentation
- 2.7 Basic information studies

Since the literature pertaining to this subject matter is so extensive, the literature search in this case had to be considered as partially peripheral. The literature cited in appendix II has been reviewed and classified by section into the same categories as indicated above.

2.2 X-RAY GENERATION EQUIPMENT

2.2.1 Interpretation of Status

X-ray generation equipment includes such components as x-ray controls and transformers, x-ray tubes, collimators and beam limiting devices, exposure control units, and phototimers.

The most common equipment that has been utilized in the United States for some time has been single phase x-ray generators; and, for most medium and heavy duty diagnostic applications, rotating anode x-ray tubes. In recent years, there has been more of a trend toward the utilization of three phase equipment and its use is now conventional for the higher energy installations. X-ray tubes have gone through a considerable evolution with regard to both their operating factors and heat capacity. This evolution has carried conventional operating potentials up to 150KV with tubes having 200,000 heat units of thermal capacity. Conventional generators have a minimum timing ratings on the order of 1/120 for single phase equipment and 1/360 of a second for three phase equipment.

With the growing use of film changer techniques, image intensification, image intensified spotfilms, and cine-radiography, a variety of exposure control devices have been introduced. Some of these affect their control in the primary circuitry and some affect their control in the high tension circuitry or at the x-ray tube itself. Automatic exposure adjustment is utilized in many forms including phototiming of films and brightness stabilization systems which obtain their control signals from the light output of an image intensifier tube.

In general, the change in this equipment for some years has been evolutionary in the extension of the factors indicated above coupled with the addition of some of the new techniques of exposure control.

2.2.2 Possibilities of Further Research

It can be reasonably expected that the x-ray industry, working with radiologists and with scientific and medical institutions, will continue the evolution of this equipment in a manner similar to that which has been historically demonstrated. It would appear however, that there are some opportunities to encourage further research in somewhat bigger steps in the areas of x-ray sources and the associated x-ray generation equipment. There are also some opportunities to further automation employed in the generation of x-rays and in the collimation of x-ray beams.

2.2.2.1 Improved X-ray Source Systems

The method of generation of x-rays has remained essentially static for several decades. A variety of suggestions have been put forth from time to time for basic or fundamental alternates in x-ray sources. Technology has made considerable advances in the area of materials and basic understanding of the physical processes involved. It is recognized that any basic alternate in this area is highly speculative from the standpoint of pos-

sible success. However, since the characteristics of the x-ray source in terms of focal spot size, intensity, and exposure time are basic limitations in information generation for radiological purposes, it is felt that research should be encouraged in this area.

The approach that might be employed to achieve these potential objectives for the improvement of x-ray sources include significantly reduced focal spot size to reduce geometric unsharpness; considerably shorter time and higher current levels to reduce motion unsharpness; the generation and utilization of narrow spectrum x-ray sources; the possibility of achieving spatial or temporal coherency of radiation in the x-ray spectrum or by achieving through diffraction, non-divergent beams.

Necessarily associated with alternate forms of x-ray sources would be alternate and compatible techniques of providing the input energy to the x-ray source and of providing suitable exposure control. The nature and potential technical difficulties of the energy supplies and exposure control equipment will necessarily vary greatly with the specific nature and type of improved x-ray source. In some cases the work on this equipment will be minimal and in other cases could be the major portion of the development of an improved x-ray source system.

2.2.2.2 Methods of Automated Exposure Determination and Set Up

In general two methods are currently used to determine the correct exposure for a given examination on a given patient. These are the manual calculation or selection of proper exposure factors with the consideration including the examination being performed, the patient and the characteristics of the receptor and any subsequent processing. The other general technique is the utilization of an energy sampling device such as a phototimer to detect a sample of the actual radiation at the receptor and to suitably control the x-ray exposure to a desired value. Even with both of these techniques in common usage, there are certain examinations where the user experiences a significant number of cases where films or examinations must be repeated due to incorrect exposure. In addition, a number of examinations must be repeated due to inadequacy of positioning in the original radiography. Any basic improvements in these areas could, for examinations where exposure errors and positioning errors are relatively high, result in lower total radiation to the patient and improved utilization of facilities. Such techniques as low energy level electronic recording for prefilming previewing to determine correct exposure factors, proper positioning and even proper localization of the phototiming sample area should be considered.

The magnetic disc techniques described in Section 2.4.2.3, Electronic Recording, may be specifically applicable to this approach. In addition to the other potential benefits cited above, there is also the implicit improvement in image quality derived from better positioning and film exposure consistency.

In addition, it would be expected that many of the steps routinely performed by the technologist in setting up an x-ray generator for an examination could be automated by punch card, computer program or other techniques to reduce the number of manual operations, and could be expected to result in improved time factors and in reliability. Since this approach would only change the mechanics of introducing the technique factors to the x-ray generator, rather than providing an improved prior determination of these factors, it would not be considered as a basic contribution.

2.2.2.3 Automatic Collimation

It has been indicated that the average radiation dose per examination could be reduced by the expedient of consistently collimating the x-ray beam to the appropriate cassette or film size or to an optionally smaller size.

To this end, automatic collimation on fluoroscopic spot-film devices is now commercially available on many different units and appears to have been well accepted.

The feasibility has also been demonstrated of using this technique for bucky radiography in conjunction with cassette size sensing equipment. This approach is well suited to standard, simplified geometries and methods which constitute a large percentage of radiographic examinations, but complications become evident when the positioning equipment to which it is applied becomes flexible enough to also allow for the less frequent situations.

Some of the technical and application difficulties which will require consideration before widespread acceptance is likely are indicated below:

1. The necessity for providing automatic and manual modes to reduce the beam size to less than the film size when necessary and to allow for unusual projections such as angled views, and the problems this creates due to possible operator tendency to routinely shut off the automatic device.
2. The problem of table-top filming.
3. The application to tilting table radiography.
4. The economics of replacing or updating equipment by large numbers of radiologists and other users of x-ray equipment as any improvements in film quality would generally be difficult to show.

2.3 POSITIONING EQUIPMENT

2.3.1 Interpretation of Status

A review of the different types of mechanical positioning equipment associated with diagnostic x-ray examinations allows the present equipment to be categorized in a variety of ways. In general, this equipment positions three elements of the radiographic or fluoroscopic system; the patient, the x-ray source, and the image receptor. Different devices are called upon to position one, two, or three of these elements simultaneously. The different groups of equipment include:

- (a) Mobile x-ray tubestands, ceiling mounted x-ray tubestands, and wall or floor-to-ceiling mounted tubestands.
- (b) Equipment stands that hold individual receptor devices such as image intensifiers.
- (c) Stretchers or tables that support only the patient.
- (d) Radiographic tables that support both patient and a cassette-holding device.
- (e) Diagnostic tables, which may be either remote or manual, and have provision for positioning patient, x-ray tube, and image receptor in one mode and patient and image receptor in another mode.
- (f) Omni-directional x-ray beam orientation units that support the x-ray tube and an opposed image receptor.
- (g) The omni-positional mount that can position the x-ray beam and receptor as in (f) above and can additionally independently position the patient in a variety of positions.

In general, a few factors categorize the majority of the positioning equipment that has been provided to the radiologist to date. First, it is almost entirely manually operated. Although motor drives are extensively used, they are almost universally manually actuated and controlled. Since many pieces of equipment have a large number of degrees-of-freedom, a lengthy sequence of these manual operations is often required. Secondly, most radiological positioning equipment has been provided to allow its use for a relatively large number of different examination procedures. Thirdly, the majority of presently used equipment requires the tableside location of the radiologist or technologist. It should also be noted that since, historically, the radiologist and the technologist have been the users of almost all of the radiological equipment, this equipment has been optimized for their uses, skills, and practices. If radiological departments of the future include significant numbers of persons with different skill levels and different methodologies, the positioning equipment must also necessarily change to optimize for this condition.

2.3.2 Possibilities of Further Research

2.3.2.1 Flexible General Purpose Remote Equipment

Flexible, general purpose remotely-operated equipment falls in category (g) of Section 2.3.1 and would have the capabilities of independently positioning both the x-ray beam and receptor and the patient support omnidirectionally in space.

The concept has been suggested of equipping a limited number of rooms in a department with highly specialized, extremely versatile remotely operated equipment so that all "special procedures" requiring complex equipment within a department can be carried out in these rooms, permitting more efficient use of the remainder for more conventional work.

As radiology has markedly expanded in scope and complexity in recent years, an increasing number of highly specialized procedures, generally utilizing fluoroscopy and radiographic contrast agents with fluoroscopic spot films, biplane serialographic studies, cine and/or magnetic tape recording, have become commonplace in most centers.

With the flexible general purpose equipment the patient being studied could be mechanically rotated in virtually any position and still remain within the fluoroscopic and/or radiographic recording field. It is argued that with this equipment, a number of procedures such as angiocardiology, myelography or pneumoencephalography could be optimally accomplished in the same radiographic room with some reduction in radiation exposure to the physicians performing the study due to his more remote location.

In considering this approach, the quite limited dose reduction possibilities, the relatively small percentage of patients undergoing radiologic examination benefitting from such a development, the cost and therefore limited application and the relatively minimal improvement in efficiency made possible by such devices must be kept in mind. Therefore, while possibly of benefit to large radiological centers, the general impact on the whole of radiology will probably be small.

2.3.2.2 Single Examination Specialized Equipment

As noted in the review of the current usage of radiological positioning equipment, little equipment is presently offered to the radiologist for highly specialized and automated use for a single examination or a small number of closely related examinations. A review of the different examinations made by radiographic means indicates that there are suitable candidates for highly standardized examinations that are routinely done in large numbers in many large institutions. It is recommended that the development of specialized apparatus in these instances be encouraged. The possible benefits include higher utilization of radiological manpower, shorter examination time for the patient, a greater reliability in obtaining successful exposures, a reduced usage of radiation for the total number of examinations performed, and a potential improvement in the technical quality of the radiographs produced.

Suitable candidates for the application of this principle might be: 1) the very short, highly routine examinations such as chest examinations and certain skeletal and abdominal radiographic examinations; 2) routine but

more time consuming examinations such as intravenous pyelograms, and 3) equipment specifically suited to the demands and caseload of the small hospital and small radiological practice. (In the instance of the chest examinations, the recommendation should not be construed as a further encouragement of the photo-fluorographic method frequently used for survey and screening examinations.)

2.3.2.3 Automated Equipment Positioning and Setup

In view of the lengthy sequence of positioning operations that a technologist is frequently required to execute in conducting a radiographic examination, it is suggested that consideration be given to the partial automation of this process. The potential benefits could be: a reduction of required time for the examinations, a greater reliability in the inclusion of all the necessary steps, and the potential reduction of error. The possibilities in this area need not be sweeping or all encompassing to be effective. In many cases, two corresponding adjustments or positionings are required and if the automation were applied to one of the elements to be controlled in response to the manual positioning of the other element, a significant improvement could result. A typical example would be the positioning of the tubestand responsive to the film location. It is suggested that this approach be considered in the cases of both specialized and general purpose equipment and in the cases of both limited automation and rather complete automation.

2.4 STATIC RECEPTOR SYSTEMS

2.4.1 Interpretation of Status

It is estimated that today in excess of 90% of all diagnostic examinations utilize full-size films as static image receptors. Most are exposed with fluorescent intensifying screens and the majority are processed in an automatic processing machine. Recent advances in these processors have reduced the processing time to one and one-half to two minutes, whereas formerly an hour or so was required for manual processing. The rapid access to diagnostic information, however, generally is not being exploited. It is used in emergency and operating rooms but for the remainder of the diagnostic radiographic procedures, the advantages are mainly administrative: higher put-through rates mean fewer processors are needed, and rapid access expedites patient flow through the radiology department by shortening the waiting time required for quality control checking of the radiographs. The logistics of patient flow, the collation of hospital records and radiographs, and the shortage of radiologists prevent maximum utilization of the rapid availability feature of modern film-process systems.

Filing, retrieving and collating the radiographs has become a serious problem in hospitals of all sizes. Lost and misfiled radiographs prevent optimum care of patients while the sheer bulk of radiographs now on file in many hospitals presents a sizable investment in storage space and an encumbrance to retrieval. Automated retrieval of full-size, reduced-size, and miniature copies of radiographs seems inevitable and is being studied by a number of groups.

The principle static receptor systems, other than conventional screen-film and non-screen systems in use today, are:

- (1) Direct miniature radiography or the photography of a fluorescent screen via lens systems of varying degrees of sophistication is used frequently for tuberculosis detection for large population units. These systems are specialized in their application, provide less radiographic information than a conventional radiograph and require higher patient exposures. For their express purpose--usually chest surveys--they provide useful diagnostic information with equipment geared to the rapid flow of patients and to provide economy of operation.
- (2) Spot-filming equipment is used in conjunction with fluoroscopy to provide static images of selected phases of a fluoroscopic examination. Conventional screen-film combinations are principally used. Film formats for image intensified spot films of 70, 90, 100 and 105 mm are used in spot filming done by photography of the output phosphor of the image intensifier. Their information content is less than that of a screen-film system but they are made with less exposure to the patient.

- (3) The Polaroid system of rapid-access radiography uses solvent transfer-pod processing with a special cassette containing a single fluorescent screen. Processing time is less than 1 minute and yields a 10 x 12-inch radiograph with the tonal scale the reverse of a conventional radiograph. The radiograph can be viewed either by reflected or transmitted light. In another form, an opaque radiographic print is produced which is viewed in reflected light. In general, the radiograph is of somewhat lower quality than conventional screen-film systems and is used principally when faster access is of prime importance.
- (4) Xeroradiography has found limited clinical application because of its low speed relative to film-screen systems. Large area contrasts are suppressed and sharp boundaries are enhanced. Studies are underway on the application of xeroradiography to mammography where lower patient exposure (compared to a non-screen exposure) and increased information are listed as advantages.
- (5) Solid state image intensification or retention panels have been developed by various investigators but none worthy of clinical application have been marketed thus far.
- (6) Rapid serial radiography bridges the gap between static and dynamic receptor systems. It is employed in diagnostic procedures where exposures in rapid sequence are needed but which require higher-information-content images than can be obtained from cine video tape or image intensifier fluoroscopic studies. Rapid serial radiography at full format is hampered by the massive equipment required to advance large films (e.g., 14" x 14") at a rapid rate while maintaining acceptable screen-to-film contact. Both sheet and roll film are used.

Reduced format serial systems are used generally with image intensification and less frequently without. They have the advantage of more rapid sequencing but at the cost of reduced information content.

2.4.2 Possibilities of Further Research

2.4.2.1 Film-Screen-Processing System Improvements

Assuming proper film processing, the screens play a more important role in radiographic image quality than do the present films. The screens are the x-ray to light energy converter elements of the system and as such are the principal source of light which produces the photographic latent image. In general, increased screen speed is attained by increased phosphor thickness so that a greater fraction of the available x-ray energy is converted into light. Greater x-ray quantum utilization from thicker screens, however, is accompanied by increased image unsharpness

(or more precisely, a loss in modulation transfer of the screens) as a result of the isotropic light emission within the depth of the screen. A study of speed, quantum utilization and screen modulation transfer suggests a reasonably invariant domain of frequency response and quantum noise relationships within which radiographic systems can be designed around a particular film.

It seems that desirable areas outside of this domain might be obtained by research on energy converters with anisotropic energy conversion. A well-known example should serve to illustrate this possibility. Cellularized screens are well documented in the patent literature but have been reduced to practice only in the laboratory or in arrays of gross fibers for use in experiments in high energy physics. However, recent advances in fiber optics technology may be applicable to cellularization in screen-film systems.

Cellularization of screens offers the following theoretical advantages: 1) high x-ray absorption with controlled image spread; 2) controlled optical spatial filtering; 3) improved quantum utilization (i.e.--more equal weighting of interactions occurring near the recorder-screen interface and in depth within the screen); and, 4) the feasibility of a single-coated instead of double-coated film. Advances made in such technology might be applicable to all radiological recording systems now using phosphor energy conversion stages. An example would be the application to image intensifiers.

Advances in film-process technology will be related to improvements in screen technology and will follow a gradual evolution consistent with the uses and needs of the radiologist. Therefore, the basic studies as outlined in section 2.7 are essential to the orderly development of film-screen-processing technology.

At the moment, there are no prominent nonsilver alternatives for conventional screen-film radiographic procedures primarily because of the high gain low noise requirements expected of static display receptors. These requirements may change with further definition of the requirements of radiology and new innovations in the field of recording.

2.4.2.2 Improved Direct Reduced Format Film Systems

Present systems utilizing a reduced format depend either on gain from an image intensifier or on greater photographic gain as in photofluorography. Both introduce sources of noise and loss of information in the information transmission chain.

It appears that not one but a combination of many improvements will be necessary to make direct miniature radiography generally applicable. Improvements in the image converter, such as cellularization, (described in section 2.4.2.1) or the use of large optically homogeneous, fluorescent crystals may be enough in themselves to greatly broaden the use of direct reduced format radiography. Such improvement, however, will place added burden on the optical transmission elements and ultimately on the film or other display media. The problem should be attacked from a

systems development point of view with elements designed to function optimally with each other.

The loss of light associated with optical reduction of image size can be offset by the use of image intensification but at present not without significant loss in spatial resolution and image contrast. In this regard, the limited contrast ratio range of current image intensifiers is a limitation to all types of image intensifiers filming compared to direct radiography. Further research and development of image intensifiers is certainly indicated for the purpose of direct reduced format radiography. (See also section 2.5.2.2)

Radiographs of significantly reduced format ultimately must be viewed by means of some projection system and as the available range of densities is increased, more stringent demands will be placed on the viewing screen, optics and flare light characteristics of the projection system. Thus, the development of improved projection systems should be considered as part of the total system. (See also section 2.6.2.3)

2.4.2.3 Electronic Recording

Static image devices using electronic recording have received little interest until recently. Principally, this has been because the interest engendered by dynamic recording devices such as cine film and magnetic tape made possible with image tubes overshadowed the possibility of using these devices for more conventional static recording. In addition, although an image intensifier and television chain could place a single image on the television screen using far less radiation than a conventional radiograph, this image is of extremely poor quality primarily because of statistical limitation and because of its transient nature.

The feasibility has been demonstrated of using a magnetic disk recorder which records the image produced on the television screen and constantly replays it through the television monitor. This image can remain on the television monitor indefinitely and be studied at leisure. For static display more radiation is used than for a single television frame but less than that for a conventional radiograph.

In addition to the principal advantage of radiation dose reduction at the expense of information reduction, another advantage of the system is immediate viewing capability for diagnosis as the image appears on the screen almost instantly.

Image clarity and resolution are not equal to a conventional radiograph. Areas of potential application are foreign body localization, fracture alignment checks and pre-filming previewing prior to radiography. As indicated in section 3.2.2.2 this latter might prove to be desirable for certain examinations to provide exposure control or improved positioning. In other applications it may be used in place of film system radiography where the immediacy of usage outweighs the higher image quality and permanency of a film record.

2.4.2.4 Immediate Access Static Receptors

Even though the rapid access capabilities of conventional radiographic systems are not being utilized fully by the radiologist, the need does exist for an immediate access static receptor system. Immediate access to the radiographic image is important in many procedures where delay may affect patient care adversely. Here, access should be instantaneous or at least in a matter of seconds after exposure. There may be secondary advantages of instant access in terms of patient handling, logistics and radiology department efficiency provided image quality is not sacrificed for the sake of reduced access time.

Conventional radiographic film-screen-process systems have made significant advances toward faster access and can be expected to continue in this direction in the future. The present requirements of film speed, format, image quality and permanence are such that basic innovations in technology appear necessary in order to attain an access time of only a few seconds for the equivalent of conventional radiography. The possibility of achieving equivalent results is more favorable when instant access techniques are considered relative to the direct reduced-format film system discussed in section 2.4.2.2. Nonsilver recording media such as those mentioned in 2.4.2.1 offer the potential of instant access but at present do not meet the joint requirements of sensitivity and image quality. Such systems, however, must be considered as future candidates for instant access.

2.4.2.5 Film and Receptor Format Standards

The factors of patient care can be influenced by film and receptor format standards. Approximately 90% of all full-size radiographs are made on only three sizes of film (i.e.-- 14" x 17", 10" x 12", and 8" x 10") and yet film manufacturers provide at least 16 different sizes of film to accommodate present radiological demands in the United States. When cine and spot filming equipment requirements are included, the number of types is greatly increased. Equipment manufacturers must contend with similar complexities to meet the diversity of requests for x-ray receptors. At least 16 sizes of cassettes are offered, many of which have a still further variety of other options. Spot filming and cine equipment inventories cover the spectrum of 16, 35, 70, 90, 100 and 105 mm films, housings and optics to accommodate various formats of different image intensifier tubes and combinations of direct or TV viewing and cine or spot filming accessories.

From a purely technical point of view such diversity appears unnecessary. If agreement could be reached by industry and the radiology profession on a few standardized formats, it would be helpful to the consumable goods and equipment manufacturers, the radiology profession and ultimately the patient. Such a consolidation of formats appears inevitable as a result of increasing international trade and the promulgation of a world-wide metric system of units and measures. The latter may provide the incentive to hasten a standard for film and receptor formats.

2.4.2.6 Integrated Filming and Processing Logistics

In most radiology departments, the function of processing the radiographic films has been considered somewhat independent from the sequence of activities involved in the diagnostic examination of the patient. The fairly general concept of using a centralized dark room to serve, if not the entire x-ray department at least a considerable section of it, has been wide spread.

A flow chart of the sequence of events involved in conducting a radiographic examination would normally include loading of cassettes in the dark room, transportation of the cassettes to the radiography room, exposing the radiograph, transporting the film back to the dark room, unloading the cassettes, processing the film, a preliminary viewing of the film to determine the technical adequacy of the examination and the release of the patient. Recently the advent of less expensive, small size, relatively low capacity but rapid automatic film processors has encouraged many institutions to consider a dispersal of the processing function to a group of suites, each serving a smaller number of examination rooms.

An examination of typical work loads in the medium and large sized hospitals shows that a relatively high percentage of the total radiographic work load can be associated with very specific examinations. Many of these examinations require relatively short times and have the capability of processing a large number of patients in a day's activity. It is recommended that the possibility of integrating, from an equipment standpoint, the making of the radiographic exposure with the identification of the film and the automatic processing of the film be explored for this class of examination. The potential benefits include a reduction in the manpower time required in the handling and transportation of the film and cassettes, a more reliable method of film identification and an improvement in patient flow times by providing more immediate technical verification of the film. This possibility appears consistent with the comments made in section 2.3 with regard to specialized positioning apparatus for individual examinations.

In addition to those situations where the identification and processing can be integrated physically into the examination apparatus, there are many other situations in large and small radiological departments where they can be integrated logistically. Consideration should be given both operationally and from the equipment standpoint of improving film flow for suite operations so that films are available when appropriate, as in some contrast media studies, during the conduct of the study, and in the remaining instances as soon after the examination as possible.

The identification process, while mentioned above as a potentially integrated part of integrated filming and processing is also worthy as a separate subject. The improvement in the reliability of film identification and the inclusion of more than a minimal identification number are felt to be conducive to improved patient care.

2.4.2.7 Retrieval Equipment, Automated Film and Filing

A review of methods utilized in film sorting, filing, and retrieval in the larger departments of radiology indicates that a minimal degree of automation is presently employed. In many instances the availability of qualified manpower for the reliable execution of these tasks is limited and in many cases the magnitude of the file contents places stresses upon the efficiency, timeliness and reliability of film handling systems. Under these conditions normal look-up time averages many minutes and, furthermore, the misfiling of a radiograph often results in its loss. It is felt that significant benefits could be derived from the standpoint of economy and health care if a considerable degree of automation could be introduced into film sorting, filing and retrieval for the institutions requiring large film files. To overcome these difficulties, a number of groups are studying approaches to automated filing and retrieval of radiographs. Three basic approaches are being followed: (1) filing of the full-sized radiograph; (2) filing of a miniature copy; and (3) filing of a reduced-size copy.

Full-Size equipment has been demonstrated for random filing and serial-search retrieval of full-size radiographs in coded folders. The folders are identified by binary and digital code and can be filed randomly in storage modules accommodating an average of 600 patient folders. This approach should reduce look-up time but will not alleviate the problem of filing a radiograph in the incorrect folder or conserve storage space. Considering the volume of radiographs already on file in most large hospitals, it is doubtful that such an approach will be employed generally for economic reasons alone.

Miniature Copies - A miniature, unit-record copy of an original radiograph offers many advantages in an automated radiograph filing and retrieving system. A unit record, perhaps in the form of an aperture card, when combined with an automated or semi-automated retrieval system now available or anticipated would decrease look-up time, reduce misfiling and greatly reduce the bulk of the storage files. With addition of a rapid means of producing duplicate film copies of the unit records, an inviolate file of radiographs and diagnostic notes could be maintained without undue inconvenience. The rapid availability of duplicate miniature copies also would facilitate the dispersal of radiographs throughout the hospital and to referring physicians. Of course, the copies and the facilities for viewing must be capable of providing adequate information.

Microfilming of radiographs has been, and is being, employed to some extent but with marginal success due largely to the general lack of convenient means for retrieving images and to the film and viewer limitations. Recent advances in film technology coupled with improved viewers offer the potential for achieving the image quality goals of a useful miniature copy system and pave the way for a fully automated unit record radiograph filing, retrieving and viewing system.

As in any information transferral system, the output of a miniature copying system will not be an exact reproduction of the input. Therefore,

the ability of a system to convey diagnostically significant information must be determined. This will likely require a statistical evaluation of performance under clinical conditions as discussed in section 3.7.

If the level of microimage quality is found adequate for diagnosis so that the original need not be viewed directly, it may be desirable to design the original recording film for microduplication purposes rather than for direct viewing.

Reduced-Size Copies - Reduced-size copies of original full-size radiographs provide another method of achieving a file film format compatible with automated filing and retrieval. Such copies could be in the size range of from 4 by 4 inches to 8 by 10 inches. The potential benefits of such an approach are lower minification ratios for improved film performance and the capability of manipulation and viewing as in the case of full-sized radiographs. A high degree of automation is possible in filing and retrieval with this size format but more file space would probably be required than for miniature size storage systems. Duplicate copies could be made if desired for multiple distribution.

Film Location - The radiograph should clearly be wherever it is most helpful in the management of the patient concerned. In some circumstances it may best be retained in the x-ray departments where the referring physician can consult with the radiologist concerning its significance. Practically, the radiograph is often most helpful if it is available to the referring physician at the patient's bedside. In the interest of the patient, the radiologist should strive to make the radiograph available for the use of the referring physician at whatever site he chooses. In doing so, of course the operation of the radiology department must not be disrupted and the radiologist must recover the film (or prepare a copy of it) for permanent reference and for comparison with future studies. These goals may be approached in three ways.

- (a) Immediate interpretation--If films are interpreted as soon as they are processed, they can be lent to the referring physician for his use at the bedside without interfering with the preparation of timely reports. In this case the film must be retrieved from the bedside for permanent storage.
- (b) Transmit images as requested from a central point--At the request of the referring physician it may be possible to transmit selected images by television from the x-ray department to the floor or patient care area. The technical problems associated with achieving this are discussed in section 2.6.2.1.
- (c) Duplicate film for distribution--Perhaps the simplest system lies in duplicating the radiographic image so that one copy may be sent to the referring physician for his use when, and however he chooses, while the original or another is retained by the x-ray department for permanent filing. This is probably the most flexible and most

promising of the systems described. The ultimate goal here would be to perfect the reduction or miniaturization of radiographic images in order that they may be filed in the x-ray department in an automated retrieval system as previously discussed. This would conserve space in the x-ray department, would facilitate the retrieval of previous films for comparison, and would make the radiographic images available to the referring physician. Such a system could well be combined with the concept of immediate film interpretation.

2.5 DYNAMIC RECEPTOR SYSTEMS

2.5.1 Interpretation of Status

Radiologic information is currently viewed or recorded dynamically by two major systems:

- (1) Regular fluoroscopic screen systems; and
- (2) Image intensifier systems.

The advent of image intensifier systems has made practical a number of new applications for the demonstration and recording of the dynamic image:

- (1) Television;
- (2) Cineradiography; and
- (3) Video tape recording.

Regular fluoroscopic screen systems have had no significant improvement since the development of the CB-2 screen, require careful dark adaptation, necessitate the use of a slightly higher radiation exposure, and are not easily adaptable for the recording of dynamic images. For these reasons they are rather rapidly being replaced by image intensifier systems.

Currently the most widely used image intensifier system is the electron optical fluoroscopic image intensifier. Systems using regular fluoroscopic screens with reflector optics, and either an image orthicon television system alone as an amplifier, using an electron optical visible light intensifier, are available but their popularity is more limited. A system using a directly x-ray sensitive television camera tube was developed but, because of numerous technical difficulties, is not in commercial production.

Closed circuit television systems for viewing the image intensifiers are in wide use and increasingly replace direct optical mirror viewing of output of these devices. Video tape recording has some use in connection with such television systems for permanent or more commonly semi-permanent retention of these images; motion picture film recording of the television image is much less widely used than video tape recording. Cineradiography is normally accomplished instead by direct film recording of the output screen of the image intensifier. Both 16 mm and 35 mm film formats are commonly used.

2.5.2 Possibility of Further Research

2.5.2.1 Fluoroscopic Screen Receptors

Further research on regular fluoroscopic screens would not appear to be productive of improvements because quantum absorption in present systems is high and increased resolution cannot be appreciated because of the inefficiencies of the eye at attainable luminance levels. Since they are being rapidly replaced by image intensifier systems further research on this type of image receptor is difficult to justify.

2.5.2.2 Image Intensifiers

There are a number of possibilities for research accomplishments leading to improvement of present electron optical image intensifier systems:

- (1) Improved quantum utilization;
- (2) Improved electron optical noise figures;
- (3) Improved resolution (modulation transfer function);
- (4) Alteration of conversion efficiency;
- (5) Improved output spectral matching;
- (6) Improved gamma; and
- (7) Improved contrast range

Research in these areas of possibility would lead to improvement in the major problem of current intensifiers; i.e., noise, poor resolution and poor contrast.

Mechanisms to increase the absorption of incident x-ray photons in the input screen resulting in improved quantum utilization would reduce the noise in these systems. However, this increase in absorption must be obtained in some fashion which does not adversely affect the resolution of the system. The possibility of using mosaic screens is an example of this approach. There is substantial noise and flare introduced into the system by the electron optical components; redesigns of these components with a view to reduction of these unwanted non-information bearing electrons would serve to increase the contrast of the image.

The modulation transfer of the intensifier system as a whole as well as each of its components should be an area of intensive research. Resolution of these systems is now approximately an order of magnitude below that of screen-film systems; this lack of resolution appears to be a basic limitation in detail visibility in dynamic recording.

Alteration of conversion efficiency has been a major effort of the recent past. Conversion efficiencies have been improved to a point where further increases with consequent decrease in x-ray quanta required for an adequate luminance on the output screen do not seem practical. That is, image quality will suffer with any significant increase in conversion efficiency due to a lack of x-ray quanta.

Signal-to-noise ratio is so small now that increase in conversion efficiency would have the effect of decreasing detail visibility. Thus, the possibility of cascaded intensifiers, for example, does not seem to be a promising approach if the result is improvement of conversion efficiency alone.

Image intensifiers currently available have output phosphors which are spectrally matched for human vision. The production of tubes with outputs spectrally matched for television camera tubes and film emulsions appears to be a productive possibility which could produce better utilization of x-ray quanta.

The contrast of present image tubes is poor and a major limitation. This effect has been briefly discussed above in relation to the "flare" of the electron-optical components.

2.5.2.3 Television Systems

Television systems may also prove to be a fertile ground for improvement by research directed specifically to their application in fluoroscopy. Possible areas of investigation are:

- (1) Improved spectral matching with the output phosphor;
- (2) Improved spatial modulation transfer function; and
- (3) Improved temporal modulation transfer function.

As with photographic materials, the relative response of a television camera tube is markedly dependent on the spectral energy distribution of the light source. Proper matching of the spectral sensitivity of the tube with the spectrum of the output phosphor would increase the overall sensitivity of the system allowing the television chain to be operated at less gain and with a more favorable signal-to-noise ratio.

At present the spatial modulation transfer of the image intensifier limits these systems but if improvements are accomplished in this area this would force improvements in the television spatial modulation transfer. Attention needs to be given to the proper matching of television bandwidth to achieve a proper resolution match without unnecessary degradation of signal-to-noise parameters.

Many television camera tubes have temporal modulation transfer which make them unsuitable for the imaging of fast moving fluoroscopic events. Development of tube types with "decreased lag" allowing for the imaging of fast events consistent with an acceptable noise figure would be a productive research area.

2.5.2.4. Unconventional Receptors

Two types of unconventional receptors seem useful to consider here:

- (1) X-ray sensitive television camera tubes; and
- (2) Solid state and planar image intensifying panels.

X-ray sensitive television camera tube development has the very significant theoretical advantage that only one quantum conversion occurs in the transformation of x-ray quanta to electrical signal. Previous development in this area failed due to technical difficulties and format, but research into newer approaches for this purpose should be rewarding.

Theoretical and practical limitations have justifiably diminished interest in solid state image intensifying panels. Certainly for the recording of dynamic phenomena the practical difficulties of coupling television cameras and cine cameras to solid state or planar panels make them less attractive as an area of research than they were in the early days of fluoroscopic image intensification.

2.5.2.5 Dynamic Recording

Two systems are in general use for recording of dynamic images:

- (1) Film, and
- (2) Magnetic tape.

There is as yet no real optimization of cine film characteristics (speed, contrast, granulation, spectral sensitivity for use with image intensifiers). There are significant areas for improvement here. There is also an unsolved developmental problem in processing of radiographic cine films in that present systems delay the utilization of the information and generally are less than photographically optimum in practice. Magnetic tape would overcome some of these problems, particularly instant accessibility, but has not achieved image quality comparable to the better image intensifier television systems or cine film systems currently used.

Two rather different factors may influence video tape in the future. First, improvements in video tape techniques may extend detail resolution and line rate capabilities too close to those of the image intensifier image quality levels. Second, recent studies have indicated that while the high performance television systems and cine recordings clearly have higher information content than present video tape recordings for images with low noise and low background and scatter radiation, these advantages may tend to be minimal in the high-noise and high-background situations commonly encountered in practical recording of dynamic information. There may well be diagnostic examinations where the differential in image quality is small and where the magnetic tape quality is adequate for the type of examination being performed. If such is the case, the advantages of immediate accessibility should result in improved patient care, improved radiological department efficiency and improved economy.

2.6 INFORMATION PRESENTATION

2.6.1 Interpretation of Status

Radiologic information is currently presented for interpretation by one of four general systems:

Direct Viewing Systems: The image recorded on the film is viewed directly against an illuminated surface. This is the most widely used type of information presentation and takes several forms such as conventional view boxes, multi-panel storage and display boxes, photo-fluorogram viewers (lens added for magnification), stereoscopic view box (prisms added), high intensity illuminators, and conventional view box with added motor drive for sequential study of roll film images.

Except for the change from incandescent to fluorescent light sources, and the change from opal glass to more durable plastic viewing surfaces, there has been no significant change in conventional illuminators in decades.

Viewing by reflected light is seldom used because of the limited density range available and does not appear to be the subject of current research for radiographic applications. Recent efforts to increase the efficiency of radiologic operation through the use of multi-panel "storage boxes" or mobile sheet-film display systems have been reported. These minimize the necessity for handling films repetitively, and transfer the task of film hanging to non-professional personnel. They in no way alter the fundamental system of information display.

Projection Systems: Images recorded on film are viewed as projected on the surface of a transmission or, more commonly, reflection screen as for cinefluorographic projection and projection of certain types of micro-films. Conventional photographic projection equipment has been modified for radiologic use. The principal concern in so doing has been to permit precise control of the speed of projection and the sequence of frames projected (i.e., single frame advance; variable speed projection; forward, reverse control). There has been little concern to date for problems of identifying a desired sequence of images on a roll film or for the correction of optical imperfections of projectors and screens.

Reflection Viewing: The observer views a mirror reflection of the fluoroscopic or radiographic image. This is most commonly seen in the mirror viewing systems of certain image amplifiers and in certain types of stereoscopic equipment.

Video Presentation: Information is displayed on the face of a cathode ray tube in the case of video presentation of fluoroscopic images, video transmission of radiographic images and video presentation of images stored on magnetic tape, disc, or in computer memory.

This field is presently subject to extensive research and development in several areas. The electronic manipulation of image characteristics, including edge enhancement, gamma enhancement, reversal of negative to

positive image, color conversion, has been the subject of many experiments. In this report the subject is considered under the title of Image Enhancement in Section III-B.

Video image transmission both within the hospital complex and over distances between radiologic departments and satellite clinics would be extremely useful if it can be accomplished with the proper image quality. Television images at present are probably not adequate for definitive diagnosis in most radiographic studies. This limits the usefulness of video image transmission.

2.6.2 Possibility of Further Research

2.6.2.1 Video Image Transmission and Display

A most promising area for development in the field of information presentation is in the area of image transmission. Its importance derives from the shortage of radiologists and the possibility that the transmission of images from satellite operations to central reading areas would increase the efficiency of the radiologist. Also, the intra-hospital transmission of images has some value in teaching and in communication between the radiologist and the referring physician. Pilot studies also suggest the possibility of transmitting images over long distance telephone lines--a much slower, but potentially cheaper, system that might be of value in some applications.

The development of improved video techniques of information presentation to permit definitive diagnosis from video images is of the utmost importance. The present state-of-the-art of video components severely limits the applicability of remote radiographic viewing. If the information content of conventional television or even high line rate, wide band width, conventional frame rate television is compared to the content of full sized radiographs a considerable difference is noted. The detail information is reduced by many times and there is a gross difference in the contrast range that can be viewed. There are techniques to improve the detail information transmitted by either using slower frame rates or by optical magnification and transmission of only a portion of the image. However, the wide contrast range of the radiograph poses a more serious problem and an effective method of transmitting the full diagnostic range has not been affected.

In view of the great amount of research in video techniques for many other purposes, an improvement of present components can be reasonably expected. Effort could properly be expended both in determining the best transmission that is practical with an optimized system composed of presently available components and in closely monitoring the improvements in video components that might permit a significant extension of quality level.

In evaluating the usability of such systems the potential diagnostic results should be compared with the specific alternate modality that is available. It may well be these are cases where immediate referral of a reduced quality image is preferable to a delayed referral of an improved

image. Consideration may also be given to the available non-television techniques of remote image transmission.

2.6.2.2 Viewing Systems

Observer response to a sensory stimulus depends both on the magnitude of the stimulus and on the observer's threshold for response at the moment. The control of glare and surround illumination--factors which influence the "threshold"--would therefore appear as important as the control of information presentation itself. This subject might for this reason offer a useful area for investigation.

The following comments relative to the limitation of conventional viewing systems should indicate some of the potential areas for improvement..

There is generally inadequate control of glare in such systems. Practical diaphragming systems haven't been developed to prevent stray light around the margins of displayed radiographic images. No effort has been made as yet to control surround luminance relative to the luminance of the radiographic display despite studies demonstrating the desirability of such control.

High intensity illumination now requires the use of auxiliary illuminators. Practical systems for varying the intensity of illumination of a radiograph, and particularly for varying the intensity of illumination of one area of a radiograph relative to another, are not generally available.

Conventional systems provide no control of image size. Despite the demonstrated value of magnification and minification, no provision for such image modification is made in conventional systems. In general, the radiologist depends on hand lenses or distance. Most conventional systems for information presentation require bulky or fixed installations unsuited to the changing demands of rapidly expanding radiologic departments.

As a practical and interim solution to the problems of remote image transmission and automated filing and retrieval, more concentration may be given to the more systematic usage of multi-panel or motor-driven film displays.

2.6.2.3 Optical Projection Systems

Optical projection systems can be subdivided into categories of usage and of mode of presentation: motion vs. still and front vs. rear projection. Equipment utilizing all combinations of these categories are in use today.

Projection systems form a vital link in the transfer of radiological information obtained at or reduced to a miniature format. Optical degradations are introduced in projection which limit transferral of information and originate from the optical elements involved. The most significant are flare light and modulation transfer losses associated with the lenses and structural elements of the projector. Flare light acts as a veiling luminance that reduces the range of brightness in the projected image and results in a loss in image contrast. Front projection screens

generally introduce little loss in image sharpness but are relatively inefficient in directing the light to the audience. However, recent advances in projection screen technology have been announced which provide controlled audience space with a significant gain in brightness. Rear projection screens introduce internal flare, losses in image sharpness, "scintillation" and "hot" spots. Screens are available in many forms which offer compromises in one or more of these deficiencies but none overcome all of them. Both rear and front projection screens now available require surround luminance control to achieve the best results.

Improved optical projection systems are useful in present radiological systems utilizing miniature photographic images (e.g. cineradiography and small format spot filming) but are of vital concern for future developments in direct reduced format radiography and automated miniature film filing and retrieval systems.

2.7 BASIC INFORMATION STUDIES

2.7.1 Interpretation of Status

The development of new information generating equipment in radiology generally proceeds along two lines of approach which differ in their basic goals. First, there is the continuing effort to create equipment which is improved from an operational standpoint. This involves modification of present equipment resulting in greater operational efficiency, and the design of new apparatus suitable for carrying out new types of radiological procedures.

Second, there is the never-ending quest to develop equipment providing improved transmission of diagnostic information or, in other words, better image quality. These efforts stem from the radiologist's need for better visualization of anatomic detail resulting in greater diagnostic certainty. Progress in this area is very slow, partly due to technical difficulties since present equipment is refined to such an extent that, in many cases, improvements in image quality will probably require technological innovation beyond the state-of-the-art.

Little is known about the relationship of observer response, which is the basis for diagnosis, with the measurable characteristics of the radiographs or image which are meaningful to the systems analyst and designer. Further, there is similarly little correlation between the usual, but ill defined term, "image quality", with either the diagnostic results or the physical characteristics of the radiographic image.

This lack of knowledge is due to the great complexity of the radiological process which begins with the x-ray exposure and ends with the diagnosis. Between these two operations, the recording of the image and its visual detection and interpretation, form essential links in the overall chain of operations constituting the radiological process. Each of these operations introduces parameters which can have a profound effect on the transmission of diagnostic information.

It is apparent that these many operations are intimately interrelated in that the output from one forms the input to the next one. Two important consequences follow from this fact. First, the diagnostic information developed and transmitted by the radiological process as a whole cannot be greater than that transmitted by any of the operations constituting the process. In order to obtain the most reliable diagnosis, therefore, each operation should be designed to degrade the diagnostically significant information put into it as little as possible.

Second, none of the operations can be optimized without sufficient knowledge regarding at least those operations with which it is interfaced. For example, it is impossible to design the best imaging and recording system without knowing what is to be imaged and how the image is read.

The interpretation of the visually detected image takes place in the brain of the radiologist and involves many intangibles; notable among which are a comparison of a given radiographic image with prior perceptual experience and expectation.

2.7.2 Possibilities of Further Research

The approach to basic information studies can be developed from a variety of standpoints. The following development is one of those possible and introduces a variety of considerations in arriving at the recommendations for specific studies in three areas.

The basic purpose of all equipment used in the radiological process is to provide information with a minimum of patient exposure, from which the radiologist can draw meaningful diagnostic conclusions with the greatest possible certainty. Radiologists and system designers need to know if present equipment fulfills this basic purpose. Before an attempt can be made to answer this general question, however, a more fundamental question needs to be answered:

What information in the radiographic image is diagnostically important?

Obviously it is difficult to design the best possible information transmitting equipment if it is not known what information is to be transmitted. In other words, it needs to be known what parts of the image the radiologist must see or, what is the diagnostically important detail in a particular radiological procedure.

Specifically, the following questions need to be investigated:

- (1) Classification of the important anatomic detail of diagnostic information in radiographic images;
- (2) Determination of their shape, size, inherent contrast, and location; and
- (3) Find those which are at the threshold of visibility and determine the reason (low contrast, unsharpness, noise).

Once these data are available, they can be used to answer the following questions:

- (1) What characteristics should the radiological process have in order to achieve maximum probability of visually detecting these anatomical elements?
- (2) Does the present process possess these characteristics?
- (3) If not, what operations limit visual detection?
- (4) Is it possible, to improve the limiting operations?

To answer these questions, each operation needs to be studied separately as follows:

- (1) In what manner does the exposing operation affect the input to the recording operation?

Information regarding diagnostically important detail should be translated into physical terms by measuring or calculating the corresponding x-ray pattern in space or the spatial frequency spectrum. The effect of kilovoltage, exposure time and geometry on these physical representations should be studied.

- (2) What should the transfer characteristics of the recording operation be for transmission of these inputs to yield the required diagnostic information?

Physical methods of measuring important noise and transfer characteristics of radiographic imaging and recording systems should be developed. These include measurement of modulation transfer function and noise power spectrum. Relationships between these physical parameters and the visual appearance of diagnostically important detail in the radiographic image must be found, since the output from the recording operation is the input to the visual detection operation.

Some of these physical techniques are being studied at present. However, they are not being related to the radiological process as a whole because information regarding diagnostically important detail is not available.

- (3) What part does the radiologist play in the radiological process?

As discussed above, since the radiologist performs the last operation in the radiological process, the final output from the process cannot contain more information than that transmitted by the radiologist.

Specifically, the following investigations regarding the visual detection process should be carried out:

- a. Determine the best method for visually scanning the radiographic image. Should it be random or should it follow a well defined pattern?
- b. Determine why certain lesions are not detected visually. Is this dependent on the visual scanning process or is it a function of the sharpness, contrast, shape, location or size of the lesion?
- c. Study the effect of ambient illumination and general viewing conditions on detail visibility.
- d. Study the inherent limitations of the visual process taking place in the eye-brain system.

To summarize, well-known concepts of communication theory should be applied to study the inherent capabilities and limitations of the radiological process as a whole. This will require knowledge of the primary input to the process which relates to the final output that is diagnostically important. The physical and psychophysical transfer characteristics essential for determining information transmission by each operation need to be identified and methods for their measurement developed.

Three broad areas of investigation can be outlined as follows:

2.7.2.1 Image Quality Related to Diagnostic Results

Determine the relationship of observer response, which is the basis for diagnosis to "image quality".

2.7.2.2 Image Quality Related to Physical Factors

Correlate "image quality" with the physically measurable characteristics of the radiographic image which are meaningful to the system analyst and designer.

2.7.2.3 Elemental Analysis of Image Formation

Develop a mathematical and physical conceptual model of the elemental and statistical process of image formation at the receptor to correlate the differential radiation absorption of the subject to the physically measurable characteristics of radiographic images.

2.8 CONCLUSIONS

In summarizing and evaluating the recommendations made in Section 2.2 through 2.7 of this report, covering the subject of Image Information Generation, several criteria were considered and are commented upon. The immediacy of the potential benefit for realization in radiologic patient care were categorized as short range (one to three years) or long range. The benefits considered were:

- (1) Reduction in radiation dose to the patient;
- (2) Improvement in image quality;
- (3) Improvement in Radiological Department efficiency; and
- (4) Economy of Radiological Department operations.

The improvements in departmental efficiency may take several forms such as, reduced usage of radiologists' time, reduced usage of supporting staff time, improved patient flow time, increased usage of equipment, improved reliability of adequate technical quality, improved timeliness of reporting, improved availability of current and prior information (including radiographic images), improved service to clinicians, and improved space utilization. Many of these improvements further imply an improvement in department economy. In general this further benefit is not separately noted and the economy comments are reserved to those areas where the benefit is more direct.

The confidence level associated with the potential success of the development is also generally indicated and a differentiation is sometimes made between technical confidence and application confidence. For certain developments additional comments seemed appropriate and have been included.

In this section the different potential areas for research that have been discussed are identified by title and section reference number and the evaluations noted. In the following section, under recommendations, the areas are selected that appeared to the Task Group to be most significant for encouragement on a short range and on a long range basis.

Section 2.2: X-Ray Generation Equipment

- (1) Improved x-ray source system (sec 2.2.2.1)

Long range
Major impact on image quality
Possible improvement in radiation dosage
Speculative

- (2) Exposure determination (sec 2.2.2.2)

Short range (technically)
Radiation reduction for certain examinations
Improved image quality for certain examinations
Some radiological department efficiency improvement
Confidence level - high technicality
Professional acceptance uncertain

(3) Automated exposure setup (Sec 2.2.2.2)

Short range

Improved radiological department efficiency

Possible radiation reduction through higher reliability of set-up

High technical confidence level

(4) Automatic Collimation (Sec. 2.2.2.3)

Short range

Radiation reduction in situations where applicable

High technical confidence, usage factors uncertain

Section 2.3 Positioning Equipment

(5) Flexible general purpose remote equipment (Sec. 2.3.2.1)

Long range

Benefits unclear

(6) Single examination specialized equipment (Sec. 2.3.2.2.)

Short range

Major improved radiological department efficiency possible

Image quality improvements

Some radiation reduction

Is partially evolving from normal interaction between industry and profession

Confidence level - high

(7) Automated equipment positioning set-up (Sec. 2.3.2.3)

Improved radiological department efficiency

Technical feasibility high on short and long range basis

Section 2.4 Static Receptor Systems

(8) Film - Screen - Processing Systems (Sec. 2.4.2.1)

Long range

Important radiation reduction

Improved image quality

Technically difficult and speculative

(9) Improved direct reduced format static receptor system (Sec. 2.4.2.2)

Long range

Improved radiological department efficiency

Improved economy

Speculative for major improvements (dependent on development of energy conversion devices)

(10) Electronic recording (Sec. 2.4.2.3)

Short range

Radiation reduction at cost of image quality

Improved radiological department efficiency

Technical confidence level high, usage and acceptance uncertain

(11) Instant Access Static Receptors (Sec. 2.4.2.4)

Long Range

Improved radiological department efficiency

Confidence level speculative without sacrifice of image quality

(12) Film and Receptor Format Standards (Sec. 2.4.2.5)

Encourages equipment and component development

Administrative benefits

(13) Integrated Filming - Processing Logistics (Sec. 2.4.2.6)

Short range

Major improved radiological department efficiency

Confidence level high

(14) Automated Film Filing and Retrieval Equipment (Sec. 2.4.2.7)

Short range

Important radiological department efficiency improvements

Confidence level, for reduced and miniature film sizes, high and dependent upon image quality

Section 2.5 Dynamic Receptor Systems

(15) Image Intensifiers (Sec. 2.5.2.2)

Long range

Major improvement of image quality

Technical confidence level - high

Currently the subject of much research

(16) Television Systems (Sec. 2.5.2.3)

Short and long range

Improved image quality

Confidence level - high

Currently the subject of much research

(see also item 19 video image transmission Sec. 2.6.2.1)

(17) Unconventional Receptors (Sec. 2.5.2.4)

Long range

Slight radiation reduction

Improved image quality

Confidence level - medium

(18) Magnetic Tape Systems (Sec. 2.5.2.5)

Short and long range
Improved radiological department efficiency
Improved economy
Confidence level - medium

Section 2.6 Information Presentation

(19) Video Image Transmission and Display (Sec. 2.6.2.1)

Short range (limited image quality)
Long range (high image quality)
Improved radiological department efficiency -
Major for high image quality
Modest for limited image quality
Confidence level - high in keeping with time range - extensive
development underway for many other applications

(20) Viewing Systems (Sec. 2.6.2.2)

Long range
Improved image quality
Confidence level low for generally - flexible, easily used
systems

(21) Optical Projection Systems (Sec. 2.6.2.3)

Long range
Improved image quality
Confidence level - high, but dependent on image quality

Section 2.7 Basic Information Studies

(22) Image Quality Related to Diagnostic Results (Sec. 2.7.2.1)

Long range
Essential to the orderly and effective improvement of radio-
logical equipment and usage

(23) Image Quality Related to Physical Factors (Sec. 2.7.2.2)

Long range
Essential to the orderly and effective improvement of radio-
logical equipment and usage

(24) Elemental Analysis of Image Formation (Sec. 2.7.2.3)

Long range
Essential to the orderly and effective improvement of radio-
logical equipment and usage

2.9 RECOMMENDATIONS

After a review of the discussions and evaluations of the 24 areas reported in Section 2.2 through 2.7, and in Section 2.8 Conclusions, the areas of image information generation that appeared to hold the most promise for major and significant contributions to radiological practices were selected for both the short-term and long-term benefit categories. These recommendations are identified below:

2.9.1 Short Range Programs

The following short-range programs are recommended as having high potential of major and significant contribution and being worthy of primary encouragement. For a fuller description of each area, reference should be made to the Section as referenced. As indicated in the foregoing discussion and conclusions, many of the other short-range programs appear worthwhile and should be encouraged if possible.

Conclusion Number	Section Number	Title
6	2.3.2.2	Single - examination specialized equipment
13	2.4.2.6	Integrated filming/processing logistics
14	2.4.2.7	Automated film filing and retrieval equipment

It can be noted that the primary justification for each of these programs is improved radiological department efficiency.

2.9.2 Long-Range Programs

The following long-range programs are recommended as having high potential of major and significant contribution and being worthy of primary encouragement. For a fuller description of each area, reference should be made to the Section as referenced. As indicated in the foregoing discussion and conclusions, many of the other long-range programs appear worthwhile and should be encouraged if possible.

Conclusion Number	Section Number	Title
1	2.2.2.1	Improved x-ray source systems
8	2.4.2.1	Film-screen-processing improvements
15	2.5.2.2	Image Intensifiers
19	2.6.2.1	Video image transmission and display
22	2.7.2.1	Image Quality related to diagnostic results

23	2.7.2.2	Image quality related to physical factors
24	2.7.2.3	Elemental analysis of image formation

It can be noted that the primary justification for the above programs is image quality in two cases, radiation reduction in one case, improved radiological department efficiency in one case and basic information development in three cases.

SECTION III

IMAGE INFORMATION EVALUATION

Summary: A report concerned with the development of information from the radiographic image, through various combinations of manual reading, image enhancement, manual or automated feature extraction, computer-aided diagnosis, manually controlled image selection or automated scanning of radiographic images. The report presents a flow chart of these highly interrelated research areas, and indicates the relative position of each area in the development of the total problem.

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SECTION III

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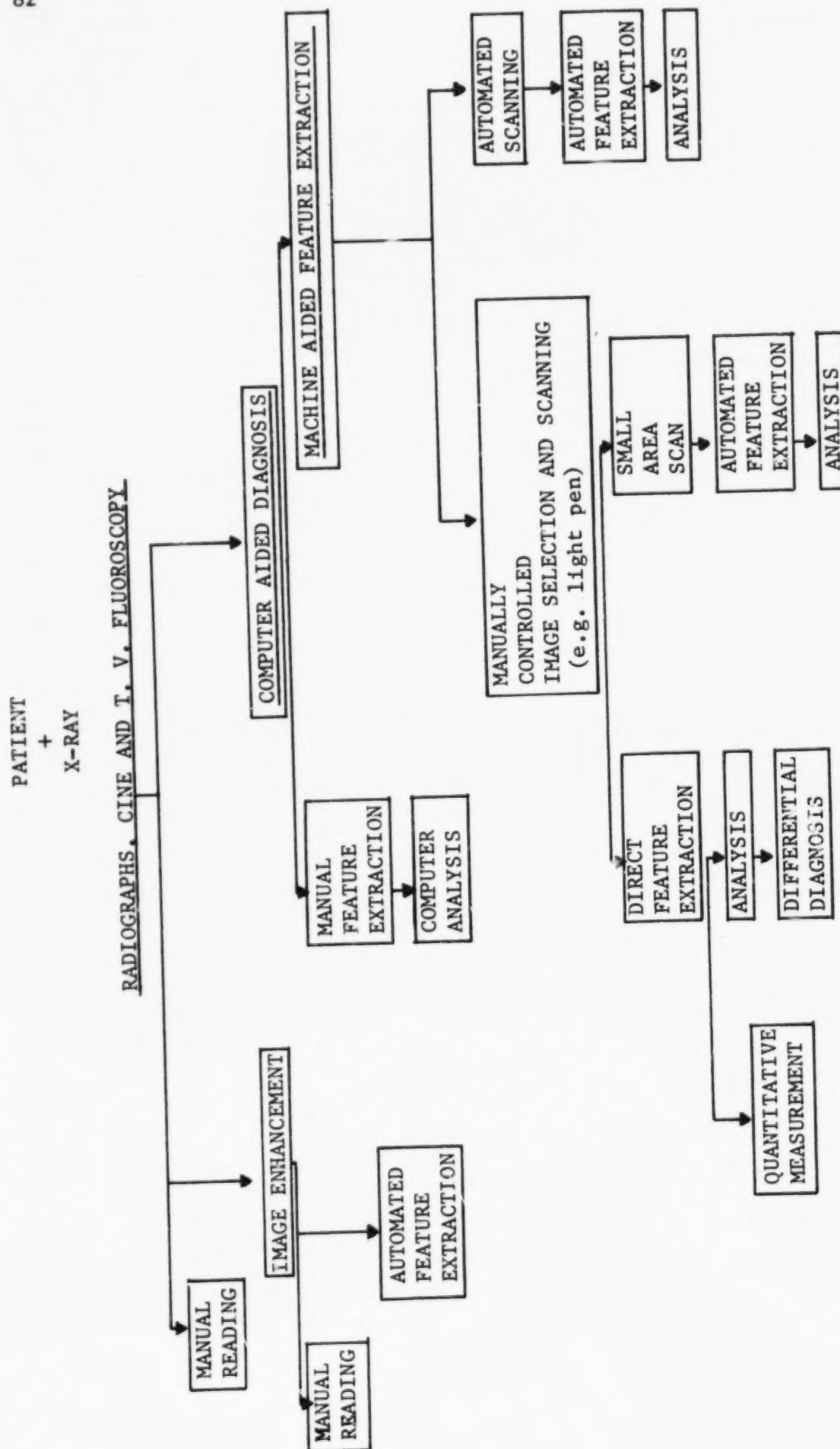
3.1 IMAGE INFORMATION EVALUATION - INTRODUCTION

Without attempting to define all of the minor variants of x-ray image portrayal, this report will limit its scope to the consideration of the three basic methods of displaying radiographic information; film radiographs, cine serial radiographs and television tape fluorography. The methods of image manipulation and interpretation considered in the subsequent sections will be applicable in almost all instances, with the necessary modifications imposed by the basic recording system.

The flow chart (page) serves as a guide to the discussion of the current status, and hopefully for the prospects of future developments in radiologic information evaluation.

Once an x-ray image has been formed, its usefulness in medical diagnosis begins with an interpretation of the image. It seems reasonable to subdivide the main image interpretation techniques into three broad categories.

- (a) Manual Reading. This method encompasses the interpretation of images studied on the view box, cine motion projection viewers and the playback television monitor.
- (b) Image Enhancement for Manual Reading. Various enhancement techniques that have been tested or proposed should be considered and discussed as an activity which may precede manual reading.
- (c) Machine Aided Analysis. In the analysis of an x-ray image, when a computer is utilized as an aid in establishing a diagnosis, the term machine-aided diagnosis applies. A computer may be used to analyze data extracted by manual techniques or to analyze data which has been extracted by semi-automatic or automatic methods from the x-ray image.



FLOW CHART

Image Information Evaluation

3.2 MANUAL INTERPRETATION

3.2.1 Manual Interpretation: Recommendations

In order to further improve the manual interpretation of radiographs, it is recommended that:

- (a) Each radiologist employ visual aids such as reducing lens and high intensity illuminators in order to perceive unsharp, low contrast shadows.
- (b) Each radiologist should analyze his sources of error of perception in order to clarify and ultimately solve them.
- (c) Periodic visual acuity tests should become a part of periodic reexamination of radiologists.
- (d) Research in the field of physiological optics, particularly relating to quantum and noise effects in human vision, should be encouraged and intensively supported.

3.2.2 Manual Reading of Roentgenograms

The manual reading of roentgenograms by radiologists forms the basis for clinical diagnostic radiographic interpretation in use today. It also forms the basis for the manual extraction of data for subsequent automated analysis. Of distinct importance to the scope of this committee, a thorough understanding of the visually perceived radiographic images will be essential for the ultimate, intelligent development of automated image analysis. The purpose of this section is to describe the current status of the manual reading of radiographs with reference to attempts which have been made to improve the perception, organization and understanding of visual radiographic images.

It has been suggested by Tuddenham¹ that our efforts to increase the accuracy of radiographic interpretation by increasing radiographic definition and contrast appears to have reached the point of diminishing returns. He suggests that errors in radiographs are derived most often from failure to organize the radiographic images effectively rather than from the ability to record the images on the roentgenograms. Subsequent attempts to study the factors affecting the sources of error in radiographic interpretation led Tuddenham and Calvert² to study the role of eye motion in the visual search process of clinical radiologists. Subsequent work by Tuddenham^{3,4} presented evidence that as much as 20 to 30% of the significant information recorded on a roentgenogram may be overlooked by the radiologist interpreting it, apparently due to ineffective utilization of the recorded details. Stressing the application of the principles of visual psychophysiology to the problems of film reading, Tuddenham offered some practical suggestions which his research indicated

would help in the better extraction of information from roentgenograms during manual reading. Starting with a properly exposed and processed radiogram, made with good conventional equipment, he stressed an approach to studying the film which included rereading the film, looking for specific diagnostic possibilities and employing a reducing lens to help perceive unsharp, low contrast shadows. He also stressed the examination of areas of high density with a high intensity illuminator, seeking a rational explanation for all shadows perceived, using supplemental radiographs and selective techniques to answer specific questions. Finally, he urged that each radiologist analyze his own sources of error of perception in order to clarify them and ultimately solve them.

Gregg's work⁵ is an example of the application of present day concepts of information content and information capacity to the interpretation of visual images. Although his work applied information theory to isotope scans, the basic tenets of information theory utilized offer an example of an area of research as yet not fully developed in the manual reading of radiographs.

A limiting factor to the present day study of the role of visio-psychophysiology to the examination of radiographic films is, as was pointed out by Morgan⁶, limited by the fact that experimental data, particularly in the field of physiological optics, are not yet available. As he stated, however, "it is sincerely hoped that radiological investigators will be in the vanguard of scientists working in the field of physiological optics, because radiologists are likely to be among the prime beneficiaries of advances in this field." If one subscribes to Dr. Morgan's viewpoint, work such as is represented by that of Dr. Rose^{7,8} on quantum and noise effects in human vision become fundamental areas of research for the radiologist.

An article which puts many of the problems of the manual reading of radiographs into perspective is that of Ardran, Crooks and O'Loughlin⁹. In the sections of their paper entitled "Predictability and Frequency of Seeing" and "Complicating Human Factors", they allude to the visual threshold for light perception, temporal summation of images and psychological considerations. They indicate that "at any of the various thresholds, insufficient illumination can result in retinal errors in perception." In addition to those previously mentioned (i.e. Frequency of Seeing) diagnostic errors may be caused by retinal and personal factors and these can be aggravated by, among other things, drugs, excessive challenge, dehydration and fatigue. They also mention the obvious, but not always appreciated, abnormalities of the eyes which may be present in radiologists which impair image perception. The effects of myopia, presbyopia and astigmatism, defects in twilight and in dark vision and the loss of translucency of the eye, which increases with age, are mentioned as important factors to be considered.

The foregoing discussion, in addition to pointing out potentially valuable areas of research in the science of the manual reading of roentgenograms, suggests the question of whether periodic visual acuity tests should become a part of a periodic re-examination of radiologists. Some credence is added to the question of age and visual acuity etc. by the

article by Fortuin¹⁰ in which the relationship between age and lighting needs is studied. The effects of glare¹¹ are also important.

Although the production of the highest quality roentgenogram is within the domain of another subcommittee, it is so intimately related to the process of manual reading that the consideration of such factors as optimum film detail¹² and density¹³ should be stressed. Also, the use of aids to study the radiographs better such as the reducing lens (as was mentioned before in Tuddenham's work) and stereoscopy¹⁴ should be stressed.

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3.3 IMAGE ENHANCEMENT

3.3.1 Image Enhancement: Summary and Recommendations

- (1) There are three main types of image enhancement systems that can be used to process radiographic data.
 - (a) Digital systems using film scanners and computers;
 - (b) Television-type systems; and
 - (c) Optical systems.
- (2) A particular enhancement procedure can be accomplished on all these systems. Each kind of system has its own particular advantages and disadvantages, depending upon the kind of enhancement operation employed.
- (3) Enhancement operations include the following: filtering, image subtraction, contrast enhancement, color translation, three dimensional reconstruction, and interpolation between motion picture frames.
- (4) Turn-around time, the time required to produce an enhanced image from the moment when its need is recognized, is now impractically long. Reduction of turn-around time can be accomplished by further research, which generally is of a very costly nature.
- (5) The enhancement of a radiographic image may be shown to be of value in a special circumstance. The total impact of image enhancement in the recognition and interpretation of disease in the clinical environment remains yet to be evaluated.

3.3.2 Image Enhancement Systems and Techniques

There exists today three main types of image enhancement systems that can be used to process radiographic data.* These are:

- (1) Digital systems using film scanners and computers;
- (2) Television-type systems; and
- (3) Optical systems.

Generally speaking, a particular enhancement operation (such as filtering) can and has been accomplished on all three systems. Depending upon the operation performed, each type of system has clear advantages or disadvantages with regard to the quality of the enhanced picture, the cost and ease of implementation and the speed of the operation.

The discussion below outlines some of the most important enhancement operations, primarily in terms of the computer approach. The discussion of the television and optical techniques is confined to some general comparisons between the three methods. A state-of-the-art review as well as any recommendation for future research in the TV and optical enhancement fields must be conducted by persons expert in these areas. Thus, the stress given to digital method is not intended to imply greater importance of digital techniques.

I DIGITAL COMPUTER IMAGE ENHANCEMENT

Computer enhancement must be preceded by some sort of film scanning and digitizing. To date, the most commonly used scanners have been the flying spot cathode-ray tube variety. However, television-type scanners and mechanical rotating prism scanners can also be used. Solid state scanners using laser beams deflected with Kerr cells or by ultrasonic methods are in an early research stage.

Many of the currently available scanners can only view images of one or two inches in size. When this is the case, an extra stage of processing to photographically reduce a full-size x-ray film must take place.

Once the image is in the computer an almost unlimited variety of processing operations can be applied. Some of the most promising types of enhancement operations are discussed below.

A. Filtering

The output of an electronic filter is obtained as some function of the past signal. In a similar way, a point in a digitized picture is filtered by replacing it with some function of the surrounding points. A simple example is to replace a point with the average of the neighboring points.

By properly selecting the way in which the neighboring points

*Chemical and photographic enhancement methods are beyond the scope of this subcommittee.

are weighted, two-dimensional digital filters may be designed to perform such functions as removing high frequency noise and sharpening detail.

Some of the filter types and their functions are as follows:

- (1) Low-pass Filters. Smooth noisy images and remove artifacts such as scan lines on isotope scan films.
- (2) High-pass Filters. Remove useless background shading that prevents contrast enhancement because of film saturation.
- (3) High-frequency Restoration Filters. Sharpen image detail. The X-ray imaging system, particularly the intensifying screen, causes fine detail to be recorded on the film with a smaller magnitude than coarse features. Digital filters can restore some of the lost signal. However, these filters also emphasize random noise.
- (4) Selective Feature Enhancement Filters. Filters can be designed to enhance or remove features with a known shape. for example, a blood vessel in an angiogram can be considered as a straight line over a short distance and a filter that enhances all straight lines can be applied.

B. Image Subtraction

Image subtraction is quite commonly used with angiographic time studies. The usual method is to subtract the pre-injection image from one or more of the later films in which the contrast material has penetrated the blood vessels in the area being filmed. Image subtraction by computer is potentially superior to other methods for finding the best match because the computer can force non-identical pictures (as might occur with a chest film sequence) to match and can find the optimum match between images of rigid structures, such as the skull, with cross-correlation techniques.

C. Contrast Enhancement

Any linear or non-linear contrast transformations can be accomplished easily with computers. For example, the film gamma characteristic can be linearized, or arbitrary transformations can be made that provide a good match between image content, film characteristics and perceptual cues.

D. Color Translation

This is a process in which each grey shade (or interval of grey) is replaced by a color in the reconstructed picture. The resultant picture provides high contrast through a color difference to areas of the picture that possessed very low black-and-white contrast in the original.

E. Miscellaneous Techniques of a Speculative Nature

- (1) Three-dimensional Reconstruction. A sequence of films taken at varying angles can theoretically be used to reconstruct a three-dimensional image, or more practically, the image intersecting any plane parallel to the film. Such methods will trade resolution for dosage since resolution will be proportional to the number of films taken at different angles.
- (2) Interpolation Between Motion Picture Frames. Cine film taken at too low a framerate causes flicker when viewed, but a high frame rate causes dosage problems. One possible solution is to expose at a low frame rate and then artificially create in-between frames using interpolation from the known frames. For example, if an object moves from position A to position B (measured relative to the film frame) on successive low rate pictures, then the object on a single interpolated frame would appear mid-way between positions A and B.

The major attraction of the computer approach to radiograph enhancement is the extreme flexibility of the system. New processing techniques and variations on existing techniques are very easily implemented, once the film scanning is available. In addition, a sequence of operations can be performed such as subtraction followed by filtering, followed by contrast enhancement, etc., without degrading the image.

Except in special cases, this is relatively difficult to achieve with analog methods. Another factor in favor of digital methods is the emergence of techniques which use computers to extract quantitative information or to recognize patterns in radiographs. For these applications, the enhancement methods discussed above become useful for preprocessing the data.

Computer image enhancement also has certain drawbacks that have prevented the research from reaching a clinically useful form. The main problems are image degradation due to scanning, slow turn-around time and high cost.

Photographic reduction of film causes considerable loss of quality and the scanning and digitizing process further degrades the image. Considering the current state of film scanning technology, it is reasonable to expect this problem to be minimized within a year or two.

Turn-around time is the time required to produce an enhanced print measured from the moment the radiologist decides he wants a film enhanced. Processing of a film may involve photographically reducing the film, scanning and digitizing the image and (usually) recording the data on digital magnetic tape, processing the picture in the computer, converting the computer output back to film and finally developing and printing the picture. This is a one or two day sequence under the best of conditions for computer image enhancement systems that exist today. Partial solution to the long turn-around time problem may be obtained by:

- (1) Eliminating photo reduction by directly scanning x-ray film with vidicon or image dissector cameras. The cameras exist today, but are not currently located where radiographic image enhancement research is being done.
- (2) Eliminating the magnetic tape recording of the scanned data by connecting the film scanner directly to the computer (this is currently done at a few places).
- (3) Providing a display directly connected to the computer for the radiologist to view. This also allows the radiologist to direct further enhancement operations after viewing early results. This could also save computing time by allowing the radiologist to enhance only a selected portion of a picture.
- (4) In cases where output film is desirable, film projection viewers would eliminate the printing step and even more important, allow the radiologist to view an image more nearly resembling the type of image he encounters.

Film scanning systems are currently very expensive, costing from \$200,000 to \$500,000 for high quality equipment. It seems clear that less expensive systems must be developed before computer image enhancement can be widely used. In the meantime, research will probably have to be accomplished in a few well-financed installations.

II ANALOG SYSTEM BASED ON TELEVISION TECHNIQUES

Television enhancement systems rely on electronic circuits operating directly on the video signal to perform the processing. Pictures may be obtained by viewing x-ray films with a TV camera or they may be obtained directly without the intermediate film by viewing fluoroscopic screens or the output of x-ray image intensifiers. One-dimensional filtering in the direction of the scan is easily accomplished electronically. Two-dimensional filters are somewhat more difficult to obtain but some progress in this direction has been made. For example, one system applies a filter that weights three scan lines that are extracted and stored in a delay line storage prior to filtering. Another system utilizes a highly de-focused scanning beam to measure background intensity and then subtracts this background from the video signal to eliminate very dark and very light areas. This is a high-pass filter as previously described.

A line-by-line subtraction of two pictures can be obtained by using two cameras and electronically subtracting the video of one from the other. If successive images are to be subtracted, the pictures can first be stored on magnetic tape or drums and then differenced.

Analog contrast enhancement methods are obvious. Other analog enhancement methods include a quasi three-dimensional display obtained by deflecting the scanning beam of the monitor of a camera a small vertical distance proportional to image intensity. Color TV can be used to obtain high contrast displays by assigning different colors to different optical density intervals when viewing monochromatic x-ray films.

Considerable work also has been done in televised stereofluoroscopy as a means of three-dimensional visualization of x-ray images.

Television methods are inherently much faster than digital methods since image conversion is unnecessary and processing requires only fractions of a second. The same type of image degradation that affects digital systems is present because of the necessity of scanning the image. This should be partially remedied as better TV cameras are developed.

Normally only one or two enhancement operations can be performed with a given TV complex so that flexibility of operation is limited. Also, successive enhancement of the same image will generally cause some image degradation in the form of decreased signal-to-noise ratio.

Once a particular type of enhancement operation is found to be medically useful, it is likely to be more easily implemented at the clinical level with analog TV techniques than with digital techniques because of the processing time differences.

III OPTICAL ENHANCEMENT TECHNIQUES

The two important optical methods are image subtraction using non-coherent light and spatial filtering using coherent light from lasers.

Optical Image Subtraction: Optical image subtraction, already used at the clinical level, involves superimposing the negative of one picture and the positive of the other picture and then exposing film with the light that passes through the two. Alignment of the two films is done manually and corrections for a misalignment such as a rotational difference is easy to accomplish optically and relatively difficult by computer. Current optical methods are fairly tedious, but relatively effective.

Spatial Filters: When coherent light (as produced by a laser) illuminates a film and then passes through a lens, an image is formed that is the square of the two-dimensional Fourier transform of the original image. A second lens transforms this frequency domain image back to the spatial domain. By blocking transmission of portions of the frequency-domain image, filtering is accomplished.

This type of filtering is a truly parallel or instantaneous operation as opposed to the serial operation of the previously discussed filters. Except for certain limitations discussed below, this represents a potentially useful method for filtering large numbers of pictures with the same filter.

One of the main limitations to laser filters today is that the film to be processed must be small-typically less than one inch, because the geometry of the lenses is very critical. Better optical systems or better photographic reduction techniques may improve this situation.

3.4 MANUAL FEATURE EXTRACTION

3.4.1 Manual Feature Extraction: Summary and Recommendations

1. Computer-aided diagnosis promises to provide a more definite and precise analysis of the information which is recorded in the radiographic image of disease. It will contribute to obtaining the maximum benefit per unit of radiation exposure by (a) minimizing diagnostic errors; (b) providing more efficient utilization of the radiologist's time; (c) improving the quality and availability of radiological health care to the nation, and (d) hopefully reducing the per unit cost of radiological services. Further (e) it will provide the logical data base for future development of automated analysis of radiographic image.
2. To become a clinically useful tool and a data base for the future, computer-aided diagnosis needs to be expanded into all disease systems. This requires that integrated studies of all such systems be carried out, in which (a) accurate public models are defined; (b) precise incidence values for both normal and pathologic states are established and (c) a key reference source of case material is made available for analysis and testing of diagnostic system.
3. In support of this research goal, the committee recommends the establishment of a Diagnostic Research Center, where residents in training, research trainees and practicing radiologists can learn about machine-mediated-diagnostic-techniques; and where research in diagnostic techniques may be initiated.
4. In conjunction with the Diagnostic Research Center, it is recommended that the following mechanism be established to extend research already accomplished, in computer-aided diagnosis.
 - (a) Appoint a panel of radiologists (an expert for each organ system or diagnostic subdivision) with the responsibility of setting policy for research, establishing the diagnostic signs to be evaluated, and interrelating studies on public models.
 - (b) Appoint a panel of pathologists (one expert for each organ system or diagnostic subdivision) to establish positive histologic proof for each case to be evaluated, and to participate in the direction of the research program.
 - (c) Develop an effective technique for collecting research material from contributing institutions. Such cases must be well documented and proved histologically. Cases would be submitted to the panels for classification and analysis, and would comprise the data base upon which research on public models, statistical analysis, and computer techniques is conducted in the Diagnostic Research Center. Such material would be available to independent investigators, within the capability of the center to provide access to it.

- (d) It is suggested that such a coordinated approach to research in computer-aided methods of diagnosis is of sufficient importance to the future of radiological health care, that it should be under the sponsorship of national organizations interested in the improvement of health care, (for example, the USPHS, the American College of Radiology, and the American Cancer Society.)

3.4.2 Manual Feature Extraction Techniques

Several groups of independent investigators have developed computer programs which serve as the basis for considering the application of computers in medical diagnosis in general and diagnostic radiology in particular. The basic features of the work to date have been data storage, incidence or frequency distribution determination, statistical testing and diagnosis based principally on Bayes' Theorem. This work has been based on man's extraction of diagnostic roentgenographic features, historical or physical examination factors or laboratory determinations. Although the methods of analysis vary slightly, the work generally follows the pattern of case analysis, parameter selection grouping of incidence values, establishing prior probabilities, statistical testing, and, finally, applying the prior probabilities to new cases to be considered for diagnosis. The following areas have been investigated:

- Bone tumors - Lodwick, et. al.
- Thyroid - Williams, et. al.
- Solitary lung nodules - Lodwick, Keats, and Templeton
- Gastric ulcer - Wilson, et. al.
- Congenital heart disease - Templeton, et. al.
- Colonic polyps - Youker, et. al.
- Mammography - Diamond and Wilson

The soundness of such an approach to radiologic diagnosis is well established. Other aims of investigation should be encouraged since this mathematically sound approach to radiologic diagnosis promises to provide a more definite and precise analysis of the disease manifestations which may be detected in radiographic images.

Direct measurements from film images and calculations based on these measurements have been demonstrated by Kricheff in intracranial calcifications and are currently under investigation in calculation of cardiac ventricular volumes and parameters of cardiac function such as stroke volume, ejection fractions and cardiac work.

The need to explore radiographic findings in order to establish incidence ranges in every phase of radiographic diagnosis is a large challenging area whose boundaries must be determined with precision to allow wide applicability of computer techniques in diagnostic radiology. These incidence values can best be determined by geographically separated radiologic experts acting in concert analyzing roentgenograms in normal and diseased conditions. Pathologic correlation must be carefully established in accord with the method outlined elsewhere in this report. To violate this principle would completely invalidate the results of these studies.

Several well-established models for differential diagnosis have been devised and these models should serve as the basis for future study and experimental designs for additional investigation. It would seem reasonable to pursue normal incidence rates in all major areas of radiology as one of prime importance. Models for study should be devised by a panel of experts and the data accumulated, processed, tested and applied in computer programs to allow initially the separation of normal from abnormal roentgenograms and later for accurate differential diagnosis of disease states.

Data extraction for the present time will be by man's inspection and recording techniques. As more sophisticated machine-linked-data-extraction-modules are devised, incidence values for these systems can be substituted into the computer programs and machine diagnosis can be accomplished.

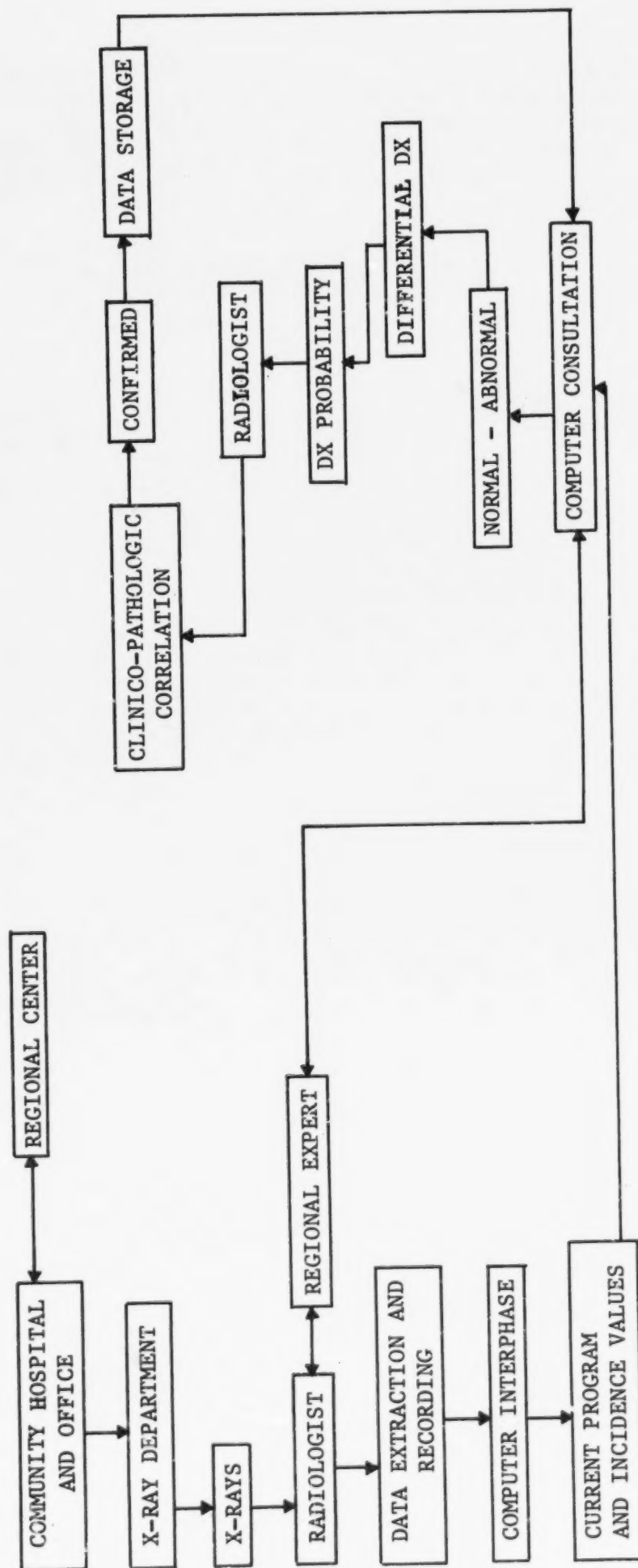
A network of computer consultation centers should be made available in order that the latest techniques and programs can be applied at the community hospital level. Teaching film strips clearly defining the public models, methods of data extraction and recording and incidence tables must be made readily available to the practicing radiologist. Every effort to erode the baseless fear of computer control of the physician should be utilized. Contract-supported experts should be freely accessible to analyze cases "on line" by television communication links to the community hospital. When consultation with the computer program is desired, prompt but not on line responses should be available.

The basic essential medical statistical technique should be clearly defined for the various programs developed and close scrutiny to statistical details maintained by a board of consulting statisticians.

Time for computer-mediated-resident-teaching and computer-aided-diagnostic-study should be made available as a part of all radiologic training programs. Courses in currently available techniques should be established in the regional centers. A central national data bank, whose facilities are made readily available to all radiologists, should be established.

The following diagram indicates the possible relationships between the practicing radiologist charged with the delivery of the bulk of patient care and the regional research center that will support his efforts. These techniques would be extremely valuable in mass-screening procedures, allowing specially trained assistants to prepare the data for computer analysis.

To accomplish the stated goals there must be logical extension of the previous work outlined above. Previous work has exemplified the basic principles of the application of the Bayes Theorem in the solution of diagnostic problems based on probability. Emanating from the Bayes operations are some incidences and some frequency distributions which can serve as reference points for future work. This has been worked out particularly in the field of bone tumors. One of the most important benefits from earlier work is the experience that has been gained in the difficult process of selection of parameters to be measured in the decision-making process. These decisions have perforce been made by individual case analysis at the viewbox without image enhancement or machine support.



Delivery of Radiological Health Care

The selection and measurement of parameters remains a basic problem and is still a vital first step which must be meticulously accomplished before the application of more sophisticated measures, certainly before any correlation with machine-scanning devices can be made. This is particularly so since the previous work has been based on a relatively small number of well-defined lesions in which the roentgenographic signs could be elicited with considerable ease. Since our methods envision the analysis of all possible roentgenographic lesions and even effective screening for "normal" versus "abnormal", at the outset it will be mandatory to set up a panel of experts to study each organ system separately and make a definitive selection of roentgenographic signs that may possibly occur in each and set them up as the basic parameters.

The evaluation of roentgenographic signs for specific diseases within an organ system, of course, will yield the information needed in the early stages for the accumulation of data against which any future analysis may be challenged. A large number of well-documented and proven cases of the disease must be obtained and analyzed by applying the parameters that had been chosen previously by the panel of experts. An analysis based on a large number of rigorously proven cases may then be programmed for computer-data storage and determinations of incidences and frequency distributions made with a high level of confidence. As many diseases as possible in a particular organ system should be analyzed in this manner in order to determine the roentgen signs that tend to recur in a particular organ system. As a catalog of such signs grows, the ability to challenge any case in a particular organ system will grow apace. Finally, the accumulated experience from the latter operations will put the radiologist in a position to discriminate "normal" from "abnormal". Certainly the latter is the most difficult operation. Ultimately even the most sophisticated automatic machine-scanning system must be taught the whole gamut of variations from the normal so that it can discriminate what is "normal".

Evaluation of the roentgenographic signs and data is a time-consuming operation. This may be aided by machine measurement, however, in the data which are straightforward, quantitative observations such as length, width, volume, distance from adjacent structures, density differences, et cetera. Such devices as the Light Pen or the Rand Tablet are obvious choices to help speed up the basic analysis of roentgenographic data. Development of such machine aids is a fruitful area for cooperative planning among the subcommittees of this task force.

The following steps are recommended as the logical extension of previous work:

1. In support of this research goal, the committee recommends the establishment of a Diagnostic Research Center, where residents in training, research trainees and practicing radiologists can learn about machine-mediated-diagnostic-techniques; and where research in diagnostic techniques may be initiated.
2. In conjunction with the Diagnostic Research Center, it is recommended that the following mechanism be established to extend research already accomplished, in computer-aided diagnosis.

- (a) Appoint a panel of radiologists (an expert for each organ system or diagnostic subdivision) with the responsibility of setting policy for research, establishing the diagnostic signs to be evaluated, and interrelating studies on public models.
- (b) Appoint a panel of pathologists (one expert for each organ system or diagnostic subdivision) to establish positive histologic proof for each case to be evaluated, and to participate in the direction of the research program.
- (c) Develop an effective technique for collecting research material from contributing institutions. Such cases must be well documented and proved histologically. Cases would be submitted to the panels for classification and analysis, and would comprise the data base upon which research on public models, statistical analysis and computer techniques is conducted in the Diagnostic Research Center. Such material would be available to independent investigators, within the capability of the center provide access to it.
- (d) It is suggested that such a coordinated approach to research in computer-aided methods of diagnosis is of sufficient importance to the future of radiological health care, that it should be under the sponsorship of national organizations interested in the improvement of health care, (for example, the USPHS, The American College of Radiology, and the American Cancer Society.)

The method of accumulation of cases for these steps is critical, and for this reason, a section describing in detail a method of data accumulation is indexed as appendix I.

3.5 MACHINE AIDED FEATURE EXTRACTION

3.5.1 Machine Aided Feature Extraction: Summary and Recommendations

1. The combination of a light pen-like device, scanner and computer can provide great flexibility for quantitative measurement of radiographic images.
2. The use of the image segment selector mechanism and computer appears to be a logical next step on the road to complete automation of x-ray diagnosis. Research in this endeavor should be encouraged and supported where possible.

3.5.2 Machine Aids For Feature Extraction

A broad field of possible machine aids are now available to assist in extracting data and identifying the features present in a radiographic image. Whenever a machine-man link is encountered, the technical problems of linkage, cost and feasibility will have to be considered. For the purposes of this report and in the context of current technology, it is probably best to consider computers, analog to digital converters, flying spot scanners, light pen input type devices and automated measurement devices as all lying within the bounds of our loose term "machines".

A. Methods Employing Manually Controlled Image Segment Selector Mechanisms

General Procedure

The examination of a visual display to extract information can be described in terms of four actions:

1. Positioning the display in the field of view.
2. Searching the display for significant features of the information that is being sought.
3. Analyzing details of the features that are found, and
4. Interpreting these features to derive the information that is available in the display.

Computer aided methods for the diagnosis of radiographs must also accomplish these actions, or their equivalent. Most of the investigations to date have employed methods that either:

- (a) Require manual positioning of the film, and manual searching for and analysis of the features. The computer is used to assign meaning to the film based upon prior statistics for the occurrence of the features that were found, as in the work of Lodwick, Wilson and others on Bone Tumors, Gastric Ulcers, etc.
- (b) Require manual pre-selection of a small section of film that is cut from the radiograph and scanned with a TV camera-like device. The scanner output is analyzed to detect signals that are characteristic of the condition

that is being studied. By pre-selecting the small section of film, the scanning is confined to the region of the radiograph that contains the condition of interest, and extraneous structure is excluded. This general procedure has been employed in the work of Rockoff and Selzer in the study of Osteoporosis by quantitative microdensitometric analysis of vertebral shadows, and in the work of Becker, Nice, et al., in the automatic determination of cardiac-thoracic ratios. In the latter study 60 mm square segments of 70 mm fluorograms were scanned with a flying spot scanner, and a digital computer was used to measure the maximum transverse diameter of the heart shadow, maximum transverse diameter of the rib cage and calculate ratios of these measured values.

The initial manual operations of both methods greatly simplify the steps that follow. In the first method (a) the mechanization is reduced to a straight-forward calculation of probabilities. In the second (b) the signal analysis is simplified by the exclusion of extraneous structure that could produce conflicting signals. In each case readily available human pattern recognition capabilities are used to direct the mechanical devices to the tasks that they are best suited to perform.

Image Segmental Selector Mechanisms

The efficiency of manual positioning and searching operations can be enhanced by the use of image selection mechanisms that have been developed and improved during the past decade. These devices can present the user with an image of the radiograph and means for selecting areas of interest within the image. The coordinates of the selected area (either a pre-defined point or the selected area's outline) can be recorded directly into a computer memory along with suitable identifying information, to be used in the analysis and interpretation.

Several different hardware configurations can be considered for this purpose. One might employ a high resolution optical scanner to create an image of the radiograph on a cathode ray tube light pen display console. The light pen can then be used to store the coordinates of the selected area and suitable fiducial marks in the computer for subsequent mechanized analysis. A significant technological limitation of this approach is the optical resolution and grey-scale fidelity of the TV scanner and display system.

A second approach might employ split beam optical projection of the x-ray image onto a transparent light pen graphic input device like the "Rand Tablet" (Grafacon 1010), and a high resolution image dissector electronic scanning device (e.g., ITT image dissector camera.) The output signals from these devices would be transmitted to a suitable data acquisition and control computer (e.g., IBM 1800 system with analog and digital I/O capabilities) which can be made to:

- accept digital position and identifying information from the light pen graphic input device

- accept digitized image intensity information from the electronic scanner in image areas prescribed by use of the light pen
- analyze the input data from the scanner and/or the light pen to extract image features that have been pre-defined for the application under consideration.

Clearly, several other state-of-the-art hardware configurations can be considered to implement such data acquisition and analysis operations. Final selection should be made on the basis of the functional requirements for the application, practical throughput rates, turn around times and cost.

B. Direct Feature Extraction

Linear Measurements

Light pens and other manually controlled image segment selector mechanism, have been used to simplify linear measurements in radiography. For example, an x-y plotting table (with digital output to a small computer) has been used by Lynch and others at Temple to determine ventricular geometry in high speed cine radiography. Measurements on individual frames of the cine record are made to determine the extent of heart valve movements and dynamic behavior of ventricular wall thickness. In other experiments the movement of gelatine coated opaque spheres has been measured on a frame to frame basis to determine the velocity and acceleration of blood passing through the heart.

Although these studies have not been made for the purpose of computer aided diagnosis, they do illustrate the potential utility of this data input approach. For example, in Wilson's work on Diagnosis of Gastric Ulcers, width and depth measurements might be made by applying a light pen to the extremities of the base and apex of the ulcer. When these coordinates are transmitted to the computer, they can be used to calculate the desired measurements and depth to width ratios. (The identification of each coordinate can be communicated to the computer by use of the alphanumeric entry capability that is provided with most light pen devices.)

Another type of direct feature observation that can be made with a light pen and image scanner combination is a shadow intensity profile taken along a line traced with the light pen. Measurements of this kind might indicate intensity variations that are not easily apparent to the eye. This mode of operation might also be useful to detecting undulations along the edge of a shadow.

Area and Volume Studies

In addition to linear measurements, a manually controlled image segment selector device can be used to trace the outline of significant shadows for computer classification of these shapes or calculation of their areas. This technique has considerable potential value in the determination of ventricular volumes from angiograms. For example, the digital computer

calculation of intracardiac ventricular volumes from orthogonal biplane x-ray images reported by Goerke and Carlsson, could be simplified if the lateral plane and anteroposterior plane images could be entered into the computer with a light pen device instead of by manual recording on scanner sheets.

An elegant mechanization of this type of measurement is now being pursued by Desilets at U.C.L.A. An Information International, Inc. PFR-3 programmed film reader is used to scan a cine-angiogram and display the first frame on a CRT monitor. The operator or radiologist traces the outline of the heart with the light pen. After this is done, the computer finds a better outline using the light pen input as a starting point. The outline for the first frame is then used as the starting point for the computer to locate the outline in the second frame, and so on. The operator does not interfere again unless he sees the computer make an error such as mistaking the aorta for the heart wall. This approach makes a significant stride in mechanization because the computer-scanner determines the outline of the area to be measured in subsequent frames as well as calculating the volume.

C. Small Area Scan Selection

The light pen, optical scanner and computer data entry mechanisms also offer means for work on limited automated scanning analysis, and combinations of direct feature extraction with automated scanning analysis. A feasible system design could provide high resolution faster scanning of small areas within the x-ray that have been defined with the light pen by the operator. In this mode of operation the user can select the scanning areas to avoid obvious extraneous structure and concentrate upon those shadows that might contain important details. Definitions of the radiographic features to be detected during the scanning mode could be tailored to suit the specific pathology that is being examined, with the quantitative tests for these features implemented in the computer. As examinations for such features are completed, the results could be accumulated in the computer with other information obtained from the medical history, physical examination, and light pen direct feature extraction operations to complete a richer analysis and computer aided diagnosis. Eventually it may be desirable to develop computer algorithms to perform the area selection function in the implementation of methods for automatic scanning of the entire x-ray. In the meantime the combined light pen and scanner approach might be used to:

- (1) - Determine some of the specific steps that the completely automatic system must perform, and
- (2) - Keep radiologists looking at films in a manner that will sustain, and perhaps improve, their diagnostic acuity.

D. Conclusion

The combination of a light pen-like device, scanner, and computer can provide great flexibility for quantitative measurement of radiographic images. With the manually controlled image selector device, the operator can use his own visual perception to locate significant items in a radiographic image and then use the mechanism to make direct quantitative

measurements of distances, areas and intensity profiles of interest. The results of these measurements go directly to the computer where they can then be interpreted according to criteria that have been selected in prior statistical studies.

Finally, use of the image segment selector mechanism and computer appears to be a logical next step on the road to complete automation of x-ray diagnosis.

3.6 AUTOMATED SCANNING

3.6.1 Automated Scanning: Summary and Recommendations

1. An automated scanning system is possible only if a systematic, overall-directed effort is made in obtaining a reliable data base (data accumulation), measurement selection techniques (roentgenographic signs selecting the measurements needed), decision schemes for classification (classifying as to normal or abnormal, or into classes of diseases), and measures of performance (confidence level of the classification reached). In short, a considerable effort must first be made in several areas before a prediction is possible as to the practicability of an automatic scanning system. Such efforts will be rewarding of themselves in assisting the radiologist towards improving his skills; such efforts will be necessary before a formal judgement is rendered regarding the feasibility of the development of a practical automatic scanning system.
2. An automated x-ray scanning system is a goal towards which the radiologist should strive. Use of the digital computer offers the most likely tool towards accomplishing this goal. Extensive efforts are needed in developing both hardware interfaces and software programs for use with the digital computer before the goal of an automated scanning system is practical.

3.6.2 Automated Image Scanning

The ultimate goal of an automated image analysis system for use by the radiologist is an automatic system which would aid in the clinical diagnosis of diseases. Such an envisioned system would be able to automatically scan roentgenograms and interface with the radiologist to determine normal and abnormal x-rays, classify diseases, and incorporate other medical findings to reinforce the classification.

An automated scanning system is possible only if a systematic overall-directed effort is made in obtaining a reliable data base (data accumulation), measurement selection techniques (roentgenographic signs selecting the measurements needed), decision schemes for classification (classifying as to normal or abnormal, or into classes of diseases), and measures of performance (confidence level of the classification reached). In short, a considerable effort must first be made in several areas before a prediction is possible as to the practicability of an automatic scanning system. Such efforts will be rewarding of themselves in assisting the radiologist towards improving his skills; such efforts will be necessary before a formal judgment is rendered regarding the feasibility of the development of a practical automatic scanning system.

1. Reliable Data Base

The necessity for a reliable data base, or data accumulation, has previously been presented. The first step towards any computer assisted or automated scanning system will be the acquisition of a reliable data base from which data may be extracted; such data is needed to determine frequency of disease occurrences, parameter

for certain diseases, and in general, a data base of sufficient size which will permit a quantitative approach towards classification of x-rays. A typical computer assisted procedure might consist of scanning an x-ray and comparing such a scan, after data processing, with a list of stored samples of given diseases and selecting the one which closest fits. Such a procedure will require reliable and carefully selected examples especially if a high confidence level is to be achieved.

2. Implementation of Accurate Measurement Systems

The most common measurement system currently in use for film scanning is a flying-spot scanner. This system has a cathode ray tube which produces a beam of light and is positioned by external signals. The light beam then passes through the x-ray, the resultant light beam then being proportional to the density of the film at a given position. The resultant light beam is monitored by a photomultiplier which then produces an electrical signal; the amplitude of the electrical signal is then proportional to the density of the film. Numerous such systems have been constructed; considerable problems exist with a flying-spot scanning system. Such problems as a spot size, lens systems, non-linearities due to scanning, varying contrast levels of individual x-rays, halo-effect of a beam spot, etc., are but a few of the problems encountered in implementing such a system.

Several measurement systems are currently being developed. Mechanical scanning systems, solid-state direct image devices, fiber-optics, and even laser devices offer the possibilities of an accurate measurement system. Such systems must be shown to be reliable, practical, and reasonable in cost for use in an automated scanning device. Development of these new image transducers should be carefully monitored with a view towards potential usage in a computer assisted or automatic scanning system.

3. Measurement Selection Techniques

The enormous amount of information available in a single x-ray film presently prohibits its storage in total. A single image on an x-ray may require a matrix of 100 x 100 points to identify, a total of 10,000 data points. Storage of such data within present computer systems requires the use of such peripheral devices as disk or tape units. It is clear that a set of measurements must be determined which allow an efficient image representation and yet not require extensive amounts of computation to determine the representation or reform the image from the representation.

A standard scheme for digital-image storage is to divide the image storage into a large number of sub-regions and record the average intensity in each of these sub-regions. If the sub-regions are rectangular and there are n rows by m columns, then nm numbers result and must be stored. In addition, the coordinates of each region must be identifiable if the image is to be

reconstructed. If each storage unit in a digital machine can assume one of q (finite) values, then there are at most q^{nm} distinct representations of this type which can be stored in the machine. It is clear the image representation schemes must be employed requiring fewer than usual storage location at the expense of having to perform a nontrivial amount of computation in order to determine the representation and/or reform an image from the representation. A suitable and efficient representation is needed for the class of images under consideration.

4. Decision Schemes for Detection and Classification

Perhaps the most significant goal an automated scanning system might achieve is to discriminate between normal and abnormal with a high degree of confidence. Such a system would allow the radiologist a more efficient utilization of his time.

Detection and classification schemes have been applied in such areas as pattern recognition systems, communication systems, and are based on a branch of statistics termed Decision Theory. A decision rule is defined which employs the data obtained from the measurement selection scheme; the decision rule selects the best possible estimate of the class which produced the data. Such decision rules may detect the presence or absence of a particular class, termed detection, or may select a particular class as being the most likely one among a number of possible classes, termed classification.

An automated scanning system will require an efficient and close to real-time decision scheme which is reliable.

5. Measures of Performance

To determine how well a system is performing a measure of performance is employed. Such measures as minimum probability of error, minimum risk, mean-square-error, are all commonly utilized. An automatic scanning system will require that the user be aware of how well the system functions, in particular, the radiologist will wish to know the confidence level of the alleged detection or classification with which an automatic image analysis system functions.

In summary, an automated x-ray scanning system is a goal towards which the radiologist should strive. Use of the digital computer offers the most likely tool towards accomplishing this goal. Extensive efforts are needed in developing both hardware interfaces and software programs for use with the digital computer before the goal of an automated scanning system is practical.

SECTION IV

IMAGE INFORMATION DELIVERY

Summary: A report concerned with automated techniques of radiological reporting, including off-line techniques and on-line interactive systems. Off-line techniques have the principal advantage of requiring a relatively unsophisticated and low cost computer facility, and can be batch processed. An on-line installation, particularly in a total hospital system, requires a highly integrated software system and a more elaborate computer. Each concept has its own particular advantages and disadvantages. The report includes recommendation of short and long range goals for the development of off-line and on-line systems.

Howard H. Barnhard, Chairman
Bernard Dimsdale
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IMAGE INFORMATION DELIVERY SUMMARY:

A. Scope and Background Information

This portion of the project revolves about the report of the radiologist. The diagnostic radiologist's report is a synthesis of his review based on radiographs (x-rays) and any additional tools employed -- fluoroscopy, television or cine image recording -- as well as patient information (history and physical findings). The report is usually typed and consists of two sometimes three parts: the main body, in which the findings are described; the conclusion, in which the diagnosis(es) is given; and, optionally, recommendations for additional or follow up examination.

One copy of this report is sent to the referring physician and/or the patient's chart, and any other copy is retained in the Radiology Department. Other copies of this report may serve to initiate the billing process or transfer diagnostic coding information to be recorded.

It is fairly simple under existing file situations to find the reports and radiographs of a particular patient. But access beyond that point is very difficult if, for example, one wishes to find all cases with a certain diagnosis or to get a statistical analysis of work done in the department.

Many numeric coding systems have been devised in order to retrieve cases. But while these are used by many departments they have been found cumbersome at best. Some diagnostic radiologists force themselves to code their patients' radiologic diagnoses but they are far outnumbered by those of their colleagues who are too busy or simply less motivated to do so. This broad variation in effort frequently exists within a single department. Other problems exist: even the dedicated radiologist may code the same case differently on separate occasions; often only the most interesting or important diagnosis is coded and other less interesting or less important diagnoses are not coded; findings are not usually coded so they cannot be correlated with the diagnoses. It would be valuable to be able to determine how often a finding or group of findings were present in a given diagnosis or with what frequency a finding(s) was found in different diagnoses.

Thus, it is no surprise that few "trust" the code system. Private lists of cherished cases come into existence and are passed from hand to hand, while the cases carefully filed in the index system are ignored.

Dissatisfaction with existing code systems also is expressed by the fact that new ones are published every few years and many unpublished modifications or totally new systems are known to exist. Unfortunately, all such systems must inevitably be a compromise between the overly "simple" approach in which too many cases fall into each broad category, and the overly "complex" one with a place for everything if one is strongly enough motivated to locate the place.

The ability to do statistical analyses is also limited since most of the code systems simply index the cases on file cards. It is possible,

however, to place some of the code systems on punch cards from which data may be extracted more easily.

The potential answer to this information dilemma rests with the digital computer. We will first examine the current state of the art and then extrapolate to the future.

B. Literature Review Summary

The digital computer has been used for several years as a tool to aid the physician in storing and retrieving medical information. Specific articles on indexing of radiologic information have been reviewed as well as those that discuss indexing and retrieval in other medical areas--valuable, since principles from these can be applied to radiology, and radiology information systems should be compatible with others in medicine. Relevant references outside the medical area are also cited.

Three computerized approaches to coding or indexing medical information have been used with success. The "narrative" method uses the medical report as ordinarily dictated. The second method is the "check-list" type in which the physician selects from the sequential presentation of multiple short lists of terms. The third method, "table look-up," is similar but involves searching longer word lists that are usually alphabetized. Some systems combine one of the last two methods with the narrative approach which is necessary in about 5 to 10% of cases if adequate expression is to be achieved.

The narrative approach places the conventionally dictated report into the computer. The radiologist's report may be fed into the computer via punched paper or magnetic tape simultaneously produced with the typed copy. This information may also be inputted by the use of optical scanning of the type-written report. Thus the radiologist functions as usual and the computer may be used off-line wherever it is available in the radiologists' community. Both of these aspects favor earlier implementation since the physicians are usually reluctant to give up a satisfactory working approach and off-line use of computers is currently more available and less expensive.

With both checklist and table look-up methods the radiologist selects from predetermined lists of possibilities. These lists may be presented to him at a remote terminal with cathode ray tube (CRT), by projection of a photographic image, or printed on paper. The goal of these systems is the creation of a brief report based on word or phrase selection and usually require that the radiologist be on-line to a computer. He may use a variety of terminal types with which to communicate varying from CRT to simple keyboard. These methods require that the radiologist change from his usual narrative approach and he must have on-line capability available to him if full advantage is to be taken of the approach.

Attempts to compare and evaluate the efficiency of the systems in retrieving information have not been reported. User evaluation of individual systems is sometimes given with the description of the system. A number of articles evaluating indexing systems in general have been reported.

C. Future Research Needs

All methods referred to require additional development and evaluation. The narrative approach has value throughout and it is important to further develop syntactic analysis. It is true that language translation by computer has been relatively unsuccessful. However, the linguistic needs for medical information handling start at a more modest level and success should be possible within a reasonable period of time.

Before developing any method in depth it would be desirable to have a better concept of the informational needs of the radiologist and the form in which his information is available. Only by such a survey may the broad potential needs be served. (A good grasp should also be obtained of existing medical and other information systems not only to assist in development but to insure compatibility.)

Once the background information is known, development with off-line and on-line approaches should include:

1. General system design and programming, including linguistic capability for handling narrative data.
2. Thesaurus and hierarchy development, eventuating in a broad base of synonym classes that will permit national standardization.
3. Prototype testing, expanded in time to other settings preferably using different computers.
4. Early evaluation of the impact of the new approach on the entire medical system, i.e., radiologist, referring physician, patient care, record keeping, et cetera.

D. Value Judgments

Radiologists badly need to have improved access to their files for better patient care, teaching, continuing education, research and administrative purposes. Work already done in radiology and other medical areas show that the computer offers considerable potential for handling this problem.

Both off-line and on-line use of the computer offer approaches to solving this problem. It seems likely that off-line approaches would be less expensive, and more readily available for several years and that continued use of the narrative approach may be more acceptable to the radiologist. In addition, off-line approaches may be so developed that on-line use is later possible.

A very important aspect of both the "check-list" and "table look-up" type of reporting by on-line use of the computer has not been significantly touched upon in the literature. Namely, no objective evaluations have been made of the effect of such new systems upon the total medical environment. Here, we are faced with the potential for many subtle influences. It is not enough for the investigator to simply report that his system "works" but rather it is incumbent upon those who espouse new systems to study their broader implications. Ideally an independent group would perform such an evaluation. Putting this matter in per-

spective from the standpoint of new approaches to diagnostic radiology reporting, the following questions might be asked:

1. Does the non-narrative approach inhibit or aid the radiologist so that he becomes less or more effective at interpretation?
2. If the radiologist becomes a button pusher or phrase selector, does his image suffer with the result that fewer physicians choose to enter the field? Or would abbreviated reporting attract more physicians since it may result in more time for consultation, teaching, et cetera?
3. Does the radiologist often have to supplement his reports with narrative statements? (If so, for effective coding of all entries, the narrative approach would have to be developed anyhow.)
4. Does the system force the radiologist to make a definite statement that masks his uncertainties and thereby misleads the referring physician, or is he forced to avoid lengthy reports that become evasive?
5. Does the lack of expressiveness of the reporting system sufficiently decrease understanding by the referring physician so he must make multiple phone calls or visits to the radiologist that use up the time of both of them?

Only by probing in this fashion can we avoid introducing systems that eventuate in more losses than gains.

One additional matter stands out as most important. Regardless of the form that any information system for diagnostic radiology takes, it is imperative that every effort be made to have it compatible with developing medical information systems in general. Further, hospital systems must be compatible not only with each other but with the outside world as well. But in this connection particularly it is essential to ensure the privacy of medical information.

E. Conclusions and Recommendations

There is a need to develop better means of handling radiologic information. Better access to this information should result in better patient care, teaching, continuing education, research and administration. The goal should be directed towards assisting radiologists at all levels from the small private office to the large teaching hospital. To do this the broad needs must be determined and the system designed with options available to meet varied practices. It may be desirable to have a national organization responsible for implementing the system throughout the country and keeping it updated.

The following phases of development are recommended:

I. Survey of Radiologists to Determine:

- A. Information needs
- B. Form of the information
- C. Computer facilities available or anticipated

This survey should cover all types of radiologic practice and be geographically widespread. It would develop new ideas of what radiologists want in the way of information and help establish priorities for development. By knowing the form of the information the system can be designed to accept the information (for example, what is the maximum number of digits used in the patient identification number). By knowing the computers available, the system may be programmed to run on the several types accessible to the greatest number of potential users.

II. Survey of Computer Information Systems

Emphasis should be on medical systems to gain ideas and ensure compatibility. But other information systems will provide similar advantages and should be probed.

III. Off-Line Operation - Systems design, prototype testing and implementation.

Off-line operation would be based on the radiologist's narrative report as input while output would be the patient's identification number and/or report. Options available would include statistical services to evaluate (a) medical data in reports and (b) administrative data. The latter might include work load distribution by diagnostic rooms and procedures to predict need for expanded facilities, or aid in quality control of technicians if each case were evaluated for such when reported.

IV. On-Line Operation - System design, prototype testing and implementation.

On-line operation could be developed around (a) narrative: conventional report system in which the radiologist expresses himself in free text, (b) check list: short report completed by selection from multiple short lists of available phrases, (c) table look-up: short report completed by selecting from long alphabetized lists of terms, or (d) a combination of (a) with (b) and (c).

The use of cathode ray tube remote terminal with typewriter and light pen would speed correction of reports when typed by a secretary. The same combination would be highly desirable if the radiologist inputs his own reports since it will speed selection of optional terms and allow narrative statements to be added on the typewriter keyboard. An on-line system would be most applicable where an entire hospital patient record keeping system had been placed in computer available memory.

Options available might include (a) remote printout and/or display (CRT) of reports, (b) CRT display of differential diagnostic possibilities based either on canned information or analysis of local diagnostic reports or both, or (c) ability to tie together several hospitals in a community to decrease costs and increase potential of system.

V. National Radiology Reference Center

A national reference service could be so specific to needs that it would only cite articles from material known to be present in the radiologist's

(institution's) library, or it could go further and actually reproduce the text on CRT or hard copy. The system might even be capable of quizzing, with permission, the memory banks of many radiologists' computers to come up with statistical answers not otherwise available.

PRIORITIES: The surveys (I & II) should be done as soon as possible followed immediately by development of an off-line system accepting the customary narrative reports (III); this represents the least expensive, most practical and acceptable approach at this time. Concurrent support should be available to help develop a variety of on-line approaches. Then when the timing seems appropriate to develop a specific on-line approach (IV) for national implementation, selection of the best system can be based on experience not speculation. The concept of a national reference center (V) is still further into the future and would depend upon the degree to which then existing library systems fill radiologists' needs.

Note Concerning Literature Review

A literature review has been printed in limited quantities as a separate volume. The literature review volume is a representative collation of abstracts and references supportive to the report of the Task Force on X-ray Image Analysis and Systems Development. The 517 page literature review volume is available from the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151. Accession number PB 182-302 should be cited. Price is \$3.00 for paper copy and \$0.65 for microfiche.

Appendix I

METHOD OF DATA ACCUMULATION (CASE ACQUISITION)
FOR COMPUTER-AIDED DIAGNOSIS IN ROENTGENOLOGYBASIC REQUIREMENT: PROVEN DATA

No matter how skillfully computer programming criteria are drawn, results will be meaningless unless the data (roentgen cases) used for evaluation are proven pathologically in a consistent manner. This consistency will be best realized by submitting the supporting pathologic specimens for all roentgen cases under study in a given field to the same group of expert pathologists for review.

DATA REQUIRED (CASE WORK-UP)1. All x-rays on the case.

Only original films should be submitted to ensure the best analysis. All originals then to be returned to the contributor after high quality photographic copying.

2. Prepared microscopic slides and tissue blocks of pertinent tissues.

A roentgen case should not be selected for submission unless representative tissue blocks (or even gross organs if necessary) are available on the case, since differential stains and other techniques may be necessary for the pathologic diagnosis. Already prepared microscopic slides are often not enough.

3. Correlating colored photographs of the gross organs or tissues studied roentgenographically.

It is essential to carefully pre-plan the gross pathology photography by orienting it in terms of the roentgen findings. This means that before the gross specimen is mounted, cut, or even removed from its environs in the body, a thoughtful review of the roentgenograms must be made to ensure the best possible correlative result. Such material is absolutely essential to the reviewing expert pathologist who must examine the tissues without benefit of having been present at the autopsy or in the operation room. In practice, this will require that the contributing radiologist be alerted so that he can go to the operating room or the morgue at the strategic moment to participate closely in the photography pre-planning.

4. A narrative summary of the clinical backgrounds to allow proper orientation and correlation.

Exact copies should be sent of all records of the patient whose roentgen work-up is selected for the data accumulation program. This will ensure the closest possible scrutiny of the case when it is being reviewed for pathologic proof. Nothing less should be tolerated.

PERSONNEL AND INSTITUTIONAL REQUIREMENTS

1. Contributing institutions, pre-selected for their specific resources, with responsibility for working up a certain quota of cases (current or on file) in designated diagnoses.

2. A central repository institution to which all cases must be forwarded for proper screening and coordination.

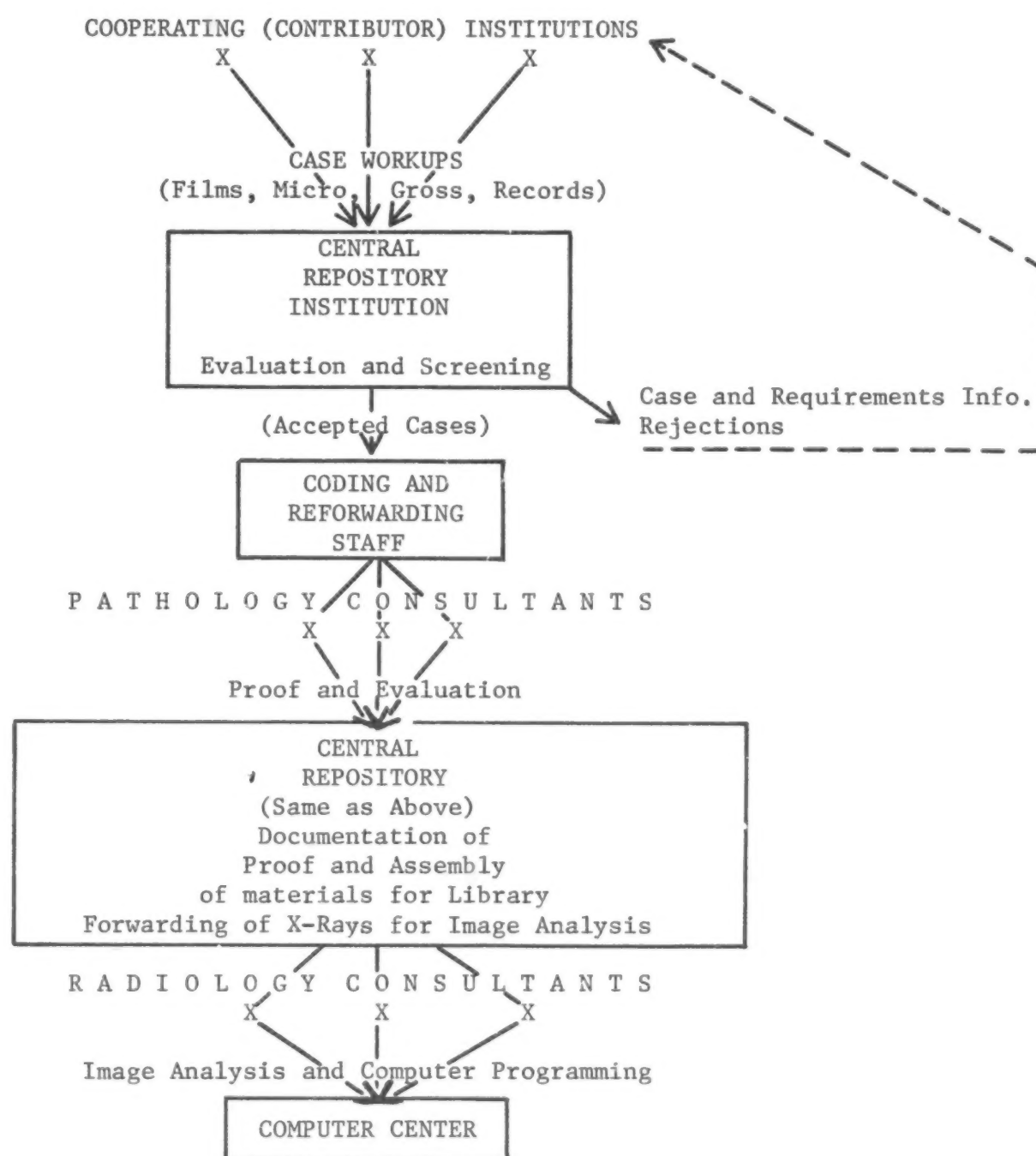
3. Coding and forwarding clerical staff located at the central repository institution and responsible for coding screened and accepted cases for re-forwarding to the cognizant consultant pathologists for proof. To overcome one of the major ethical hurdles in practice, the cases would be sent coded to the consultant pathologists without the latter knowing the institutions of origin.

4. Consultant pathologists, appointed for their expertise in given fields upon whom rests the responsibility for consistent proof of all cases used for computer evaluation. Their physical location will, of necessity, be varied since their selection will be based on their expertise and availability rather than on geographical location. This makes a central repository screening institution (2. and 3. above) mandatory.

5. Consultant radiologists, again appointed for their expertise in given fields, responsible for the final image analysis and computer programming of the selected proven cases. The central repository and coordinating institution will forward x-rays to these consultant radiologists when proof has been received from the consultant pathologists.

6. Computer Center, responsible for storage and retrieval of all data worked up by the consultants. Free access to data by all interested parties is mandatory for the successful functioning of the program.

FLOW DIAGRAM (DATA ACCUMULATION)



The ABSTRACT CARDS below are designed to facilitate document retrieval using Coordinate Indexing. They provide space for an accession number (to be filled in by the user), suggested key words, bibliographic information, and an abstract.

The Coordinate Index concept of reference material filing is readily adaptable to a variety of filing systems. Coordinate Indexing is described in the publication "IBM Data Processing Techniques - Index Organization for Information Retrieval" (C 20-8062). Copies are available through IBM Branch Offices.

The cards are furnished in triplicate to allow for flexibility in their use (e.g., author card index, accession number card index).

REPORT OF THE TASK FORCE ON X-RAY IMAGE
ANALYSIS AND SYSTEMS DEVELOPMENT, PHS
Contract PH 86-67-198; University of Missouri;
July 1968; DMRE 69-1; BRH, PHS, DHEW.

Accession No.

A task force of outstanding experts in radiology, engineering, and computer science was formed under Public Health Service contract with the University of Missouri. Its purpose was to study the functional organization and status of diagnostic radiology from a perspective of increasing the effectiveness of radiological systems while obtaining the maximum amount of diagnostic benefit per unit of radiation exposure. This report details the findings and recommendations of the task force.

KEY WORDS:

X-ray, Radiology, Diagnosis, Image Analysis

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